

IoT Product Design and Rapid Prototyping

Brian Rashap

February 2025

Class Logistics



Brian Rashap, Ph.D.

- Proud husband of Krista and father of Shelby (26) and Ethan (22)
- Electrical Engineer (Michigan) with 25 years industrial experience (Intel)
- Hobbies: running, cycling, reading, spending time with family





Edward (EJ) Ishman

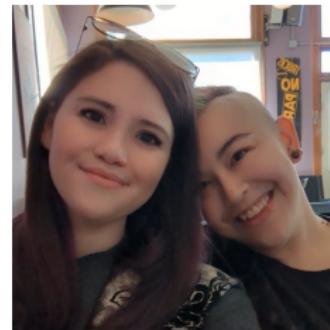
- Loving father of two exceptional children Ziona (9) and Ivey (7)
- 4 years as an Aerospace Maintenance Journeyman (Crew Chief) in the United States Air Force
- CNM Ingenuity IoT Bootcamp graduate (Cohort 6)
- Hobbies: Photography, Live entertainment, exploring the outdoors, thrifting.





Jamie Dowden-Duarte

- CNM student, NSLS, PTK, stemCore, admin officer ECOS, SWE
- IoT Bootcamp Graduate (cohort 14)
- USN veteran LHD3 USS KEARSARGE
- Hobbies: painting, shooting guns, hiking





Student Introductions

- Your name
- What were you up to before starting the bootcamp
- Any prior experience with programming, electronics, 3D modeling
- What do you hope to get out of the bootcamp



Class Rules

- Respect each other. Help each other.
- Ask questions.
- Be on time (let us know via Slack if you won't be here)
- Keep your workspace and the classroom neat and tidy.
- If you are struggling, let us know. We are here to HELP!
- Class hours
 - Mon-Th: 8am to 5pm ¹ and Friday: 8am to 3pm ²
 - Lunch Break: 1 hour near noon. Maybe combined with work time.
 - Please respect the instructors' lunch break as well.
- Phone Policy: phones should not be out or used during class
 - No gaming, no surfing social media
 - If you need to take/make a call, please set out of the classroom
 - Exceptions: two-factor authentication, pictures of projects, class videos

¹Doors open at 7:50, please be in your seats ready to learn by 8:00

²Occasionally on Friday there will be optional activities from 3 to 5



Grading

Assignments total 1000 points. 75% (or 750 points) needed to graduate.

Point distribution

- ① IoT assignments + Lab Notebooks: 300 points ³
- ② 3D modeling (Solidworks) assignments: 100 points
- ③ Weekly quizzes: 100 points
- ④ Midterm Projects: Smart Room Controller/Plant Watering System:
100 points each (200 total)
- ⑤ Team Capstone Project: 250 points
- ⑥ Professional Development: 50 points

³All coding assignments must follow style-guide



Credit for Prior Learning (CPL)

Approved for CPL	
CIS 1605	Internet of Things
CIS 1275	Introduction to C++
BCIS 1110	Fundamentals of Information Literacy and Systems
BUSA 1130	Business Professionalism
BUSA 1198	Project Management Fundamentals
CSIS 1151	Intro to Programming for Non-Majors of CS*
* CSIS 1151 credit requires appropriate math prerequisites	



Foundation of lean Certificate





IPC Solder Certification



**IPC-J-STD-001 Rev.
H, Certification**

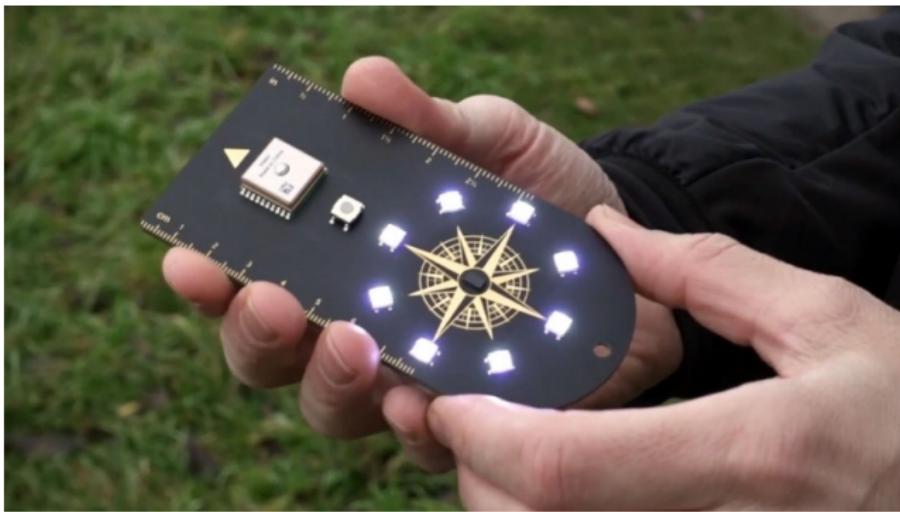
Introduction



"THE CHANGING OF THE PASSWORDS
HAS BECOME A DAILY EVENT."



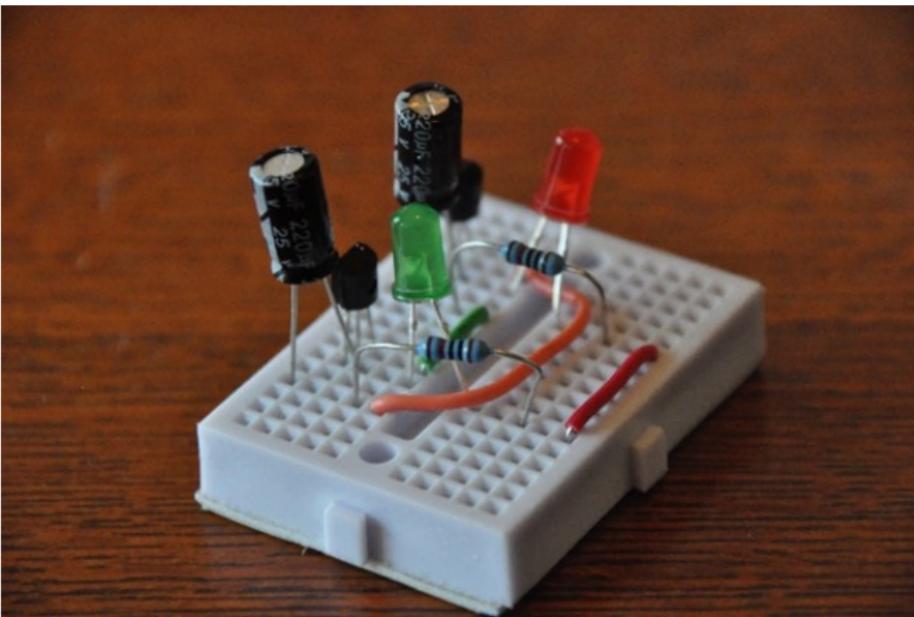
Pizza Finder



<https://www.youtube.com/watch?v=aY00t0y6lcE&t=6s>

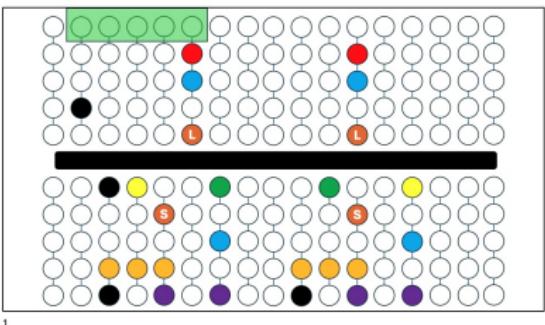
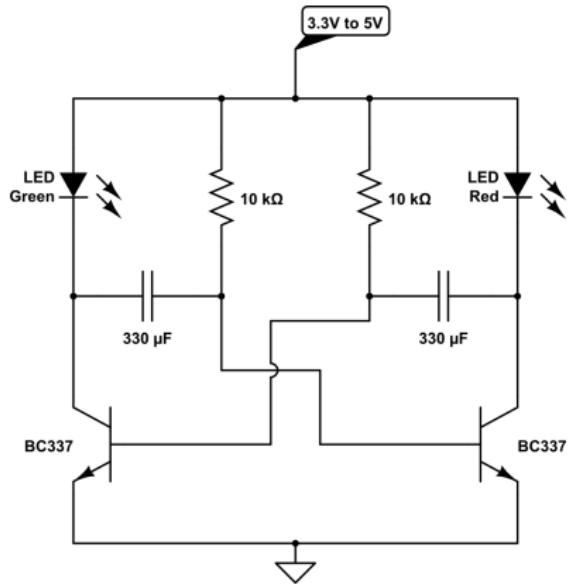


Let's Build Something

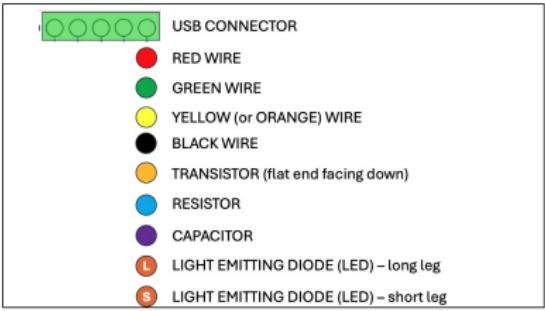




Oscillator: Flip Flop



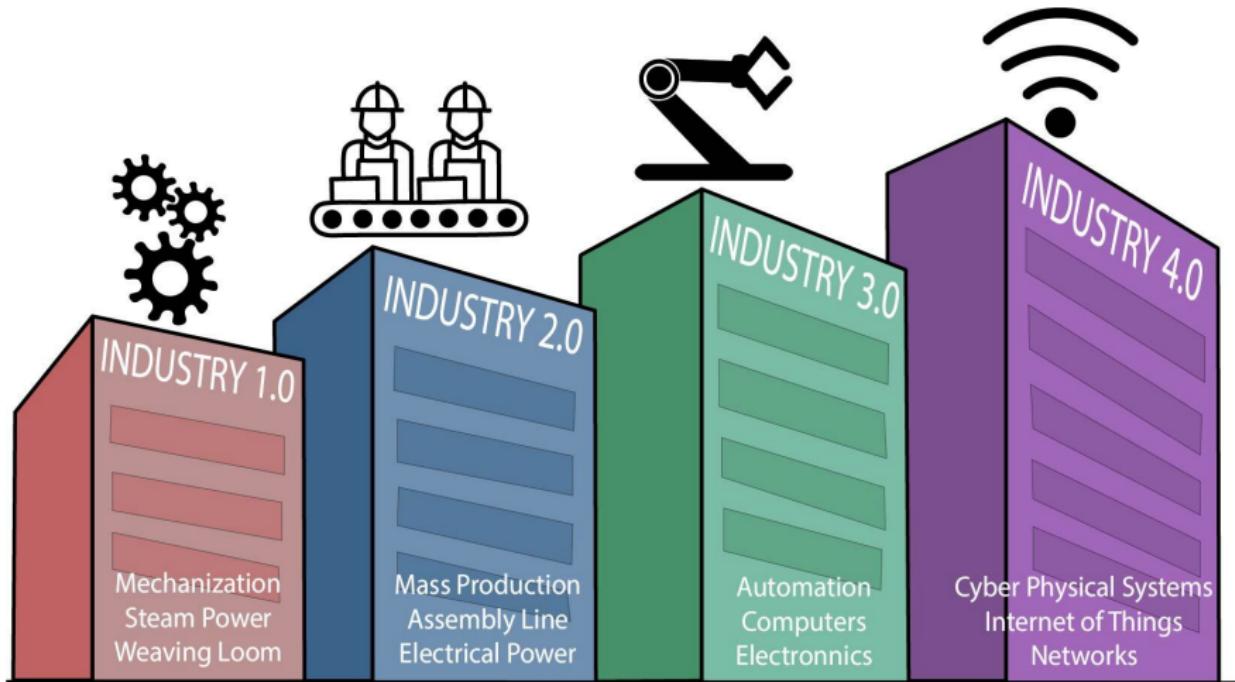
1



2

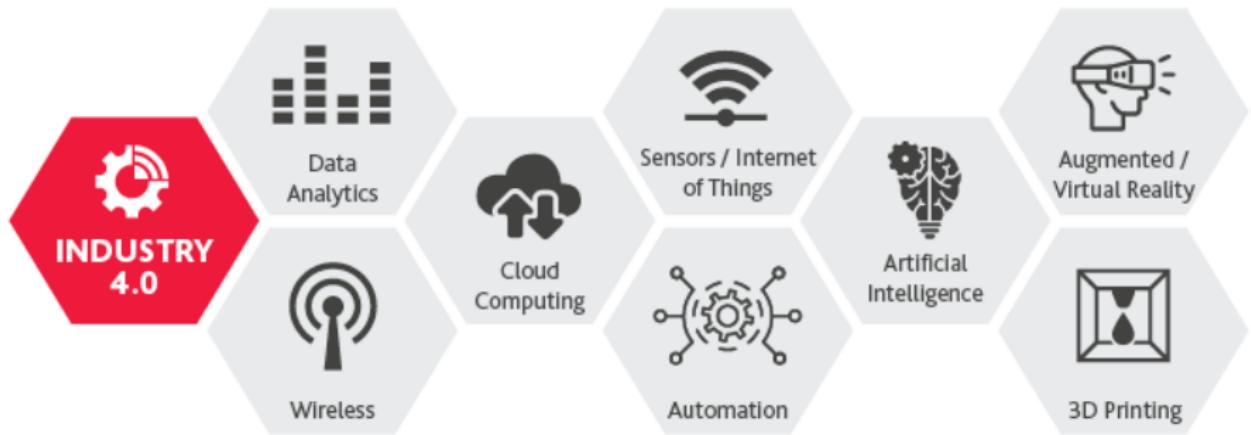


Evolution of Industry



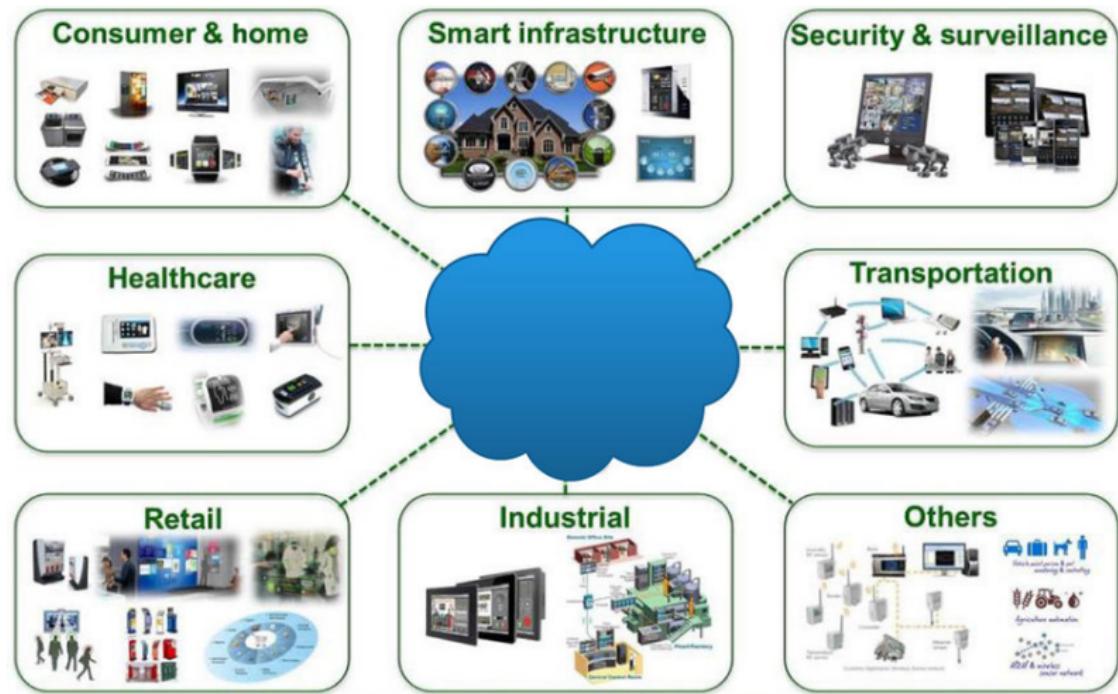


Components of Industry 4.0



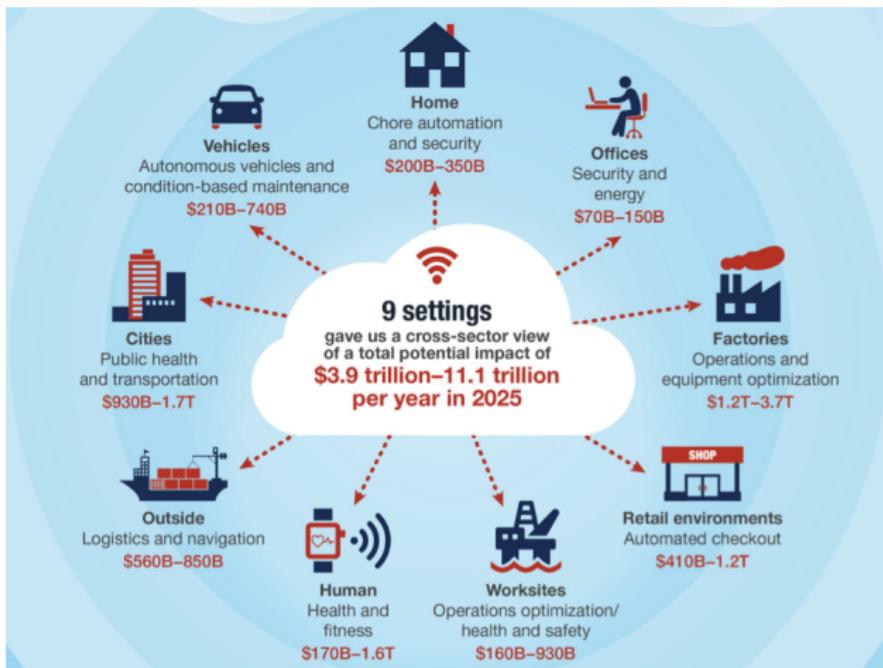


What Is the Internet of Things





IoT 2025



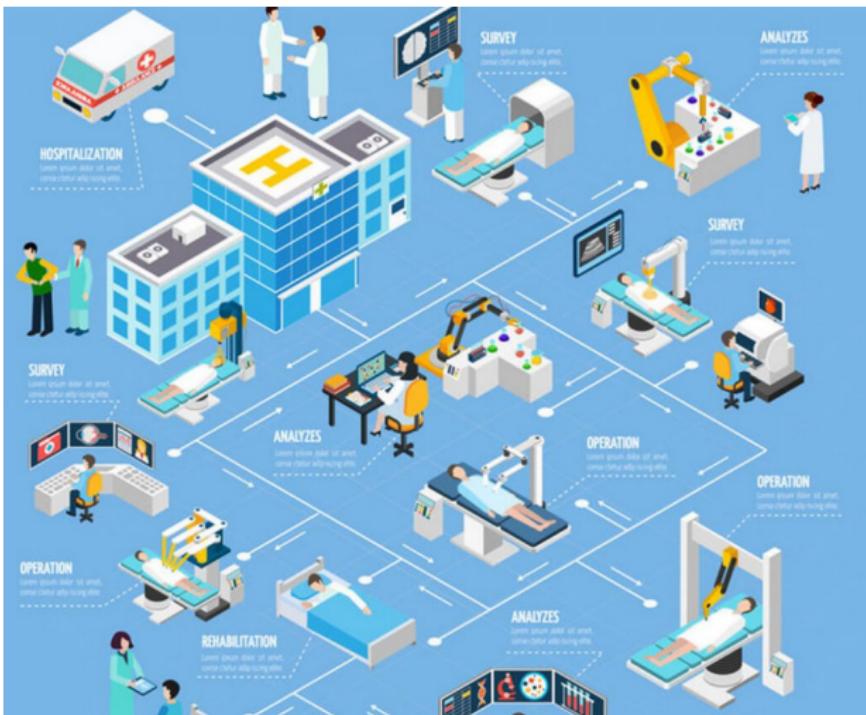


Smart Facilities





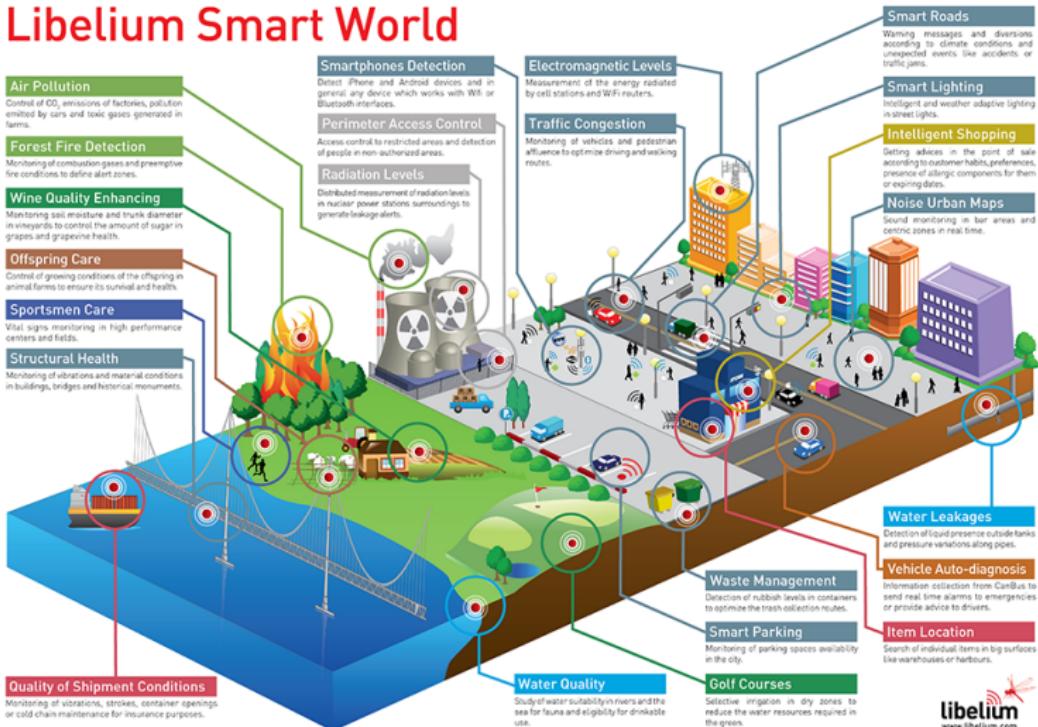
Healthcare 2025





Smart World

Libelium Smart World





And Out of This World





IoT and Data Science



AI: Data-based learning



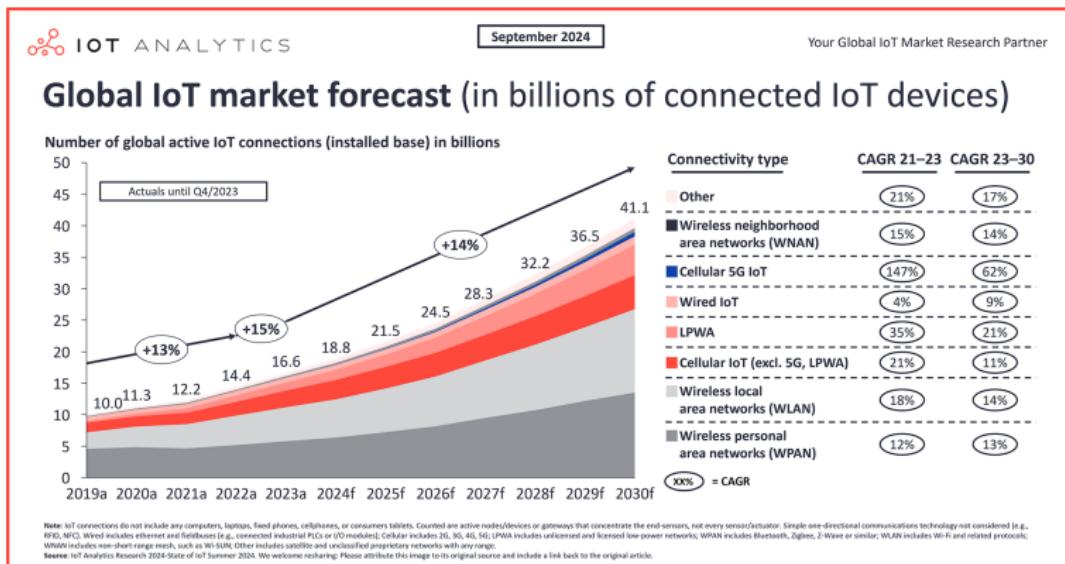
Big Data: Capture, storage, analysis of data



IOT: Data Collection through IoT



How Big Will IoT Be



How ubiquitous is the Internet of Things?

- There are approximately 20 billion IoT devices today.
- 127 new IoT devices are connected to the internet every SECOND.
- This morning, 1,828,800 IoT devices will be added to the internet.

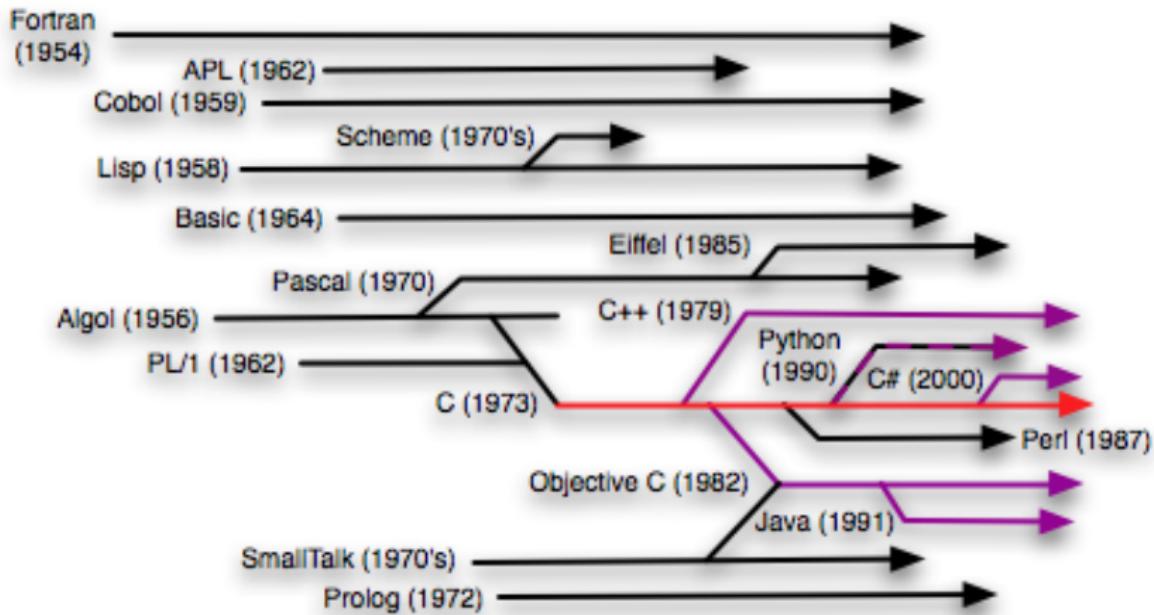


Let's Begin Our Journey





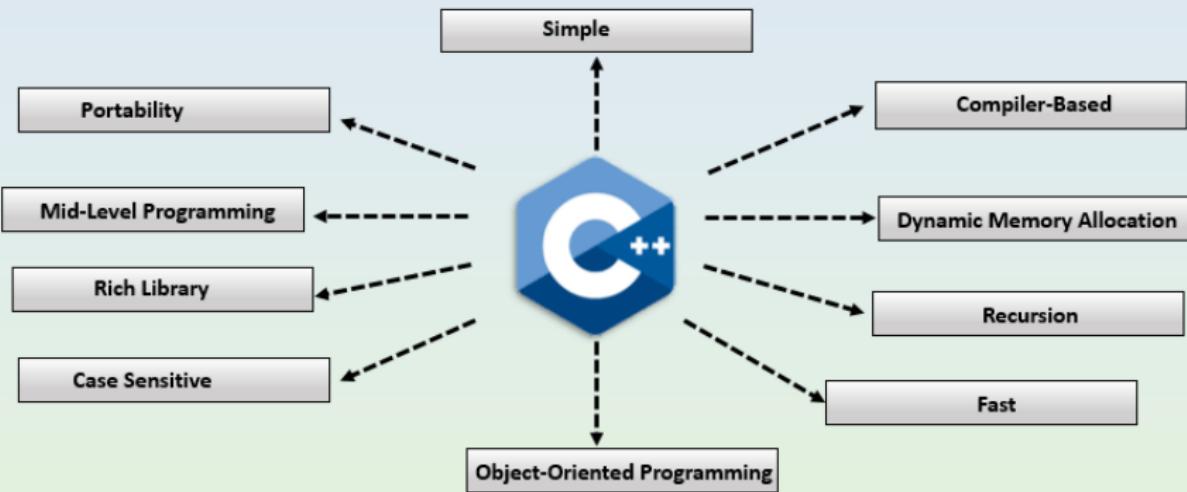
Computer Languages





Why C++

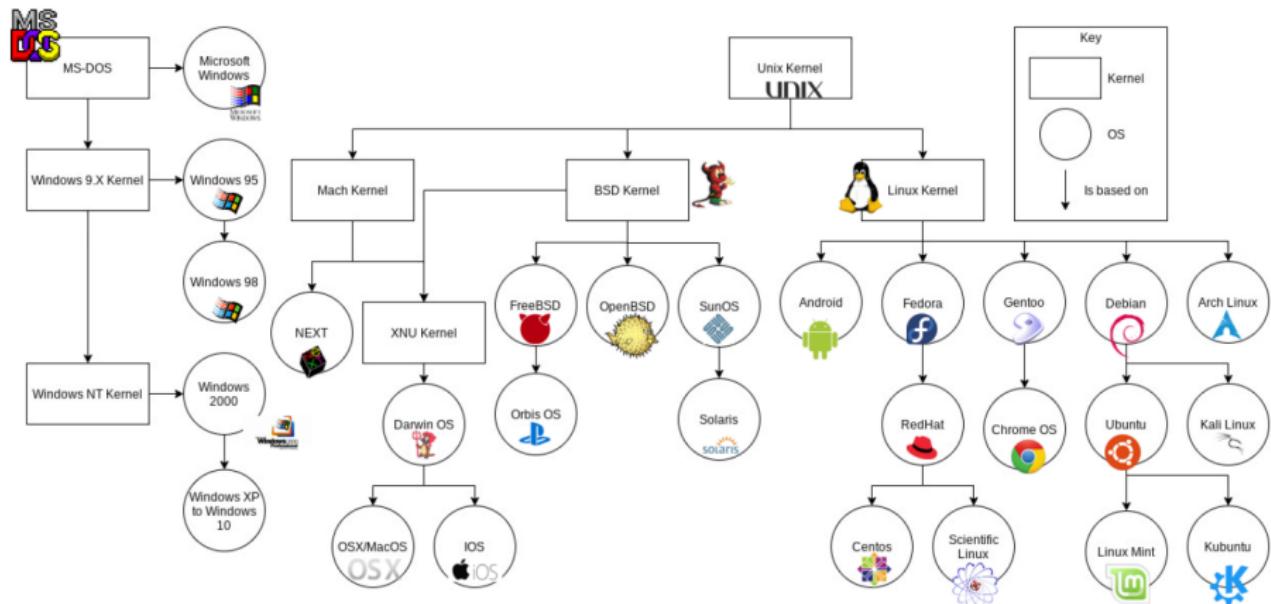
Features of C++



www.educba.com



Operating Systems





CLI vs GUI

```
[root@localhost ~]# cd /var  
[root@localhost var]# ls -la  
total 72  
drwxr-xr-x. 18 root root 4096 Jul 30 22:43 .  
drwxr-xr-x. 23 root root 4096 Sep 14 20:42 ..  
drwxr-xr-x. 2 root root 4096 May 14 00:15 account  
drwxr-xr-x. 11 root root 4096 Jul 31 22:26 cache  
drwxr-xr-x. 3 root root 4096 May 18 16:03 db  
drwxr-xr-x. 3 root root 4096 May 18 16:03 empty  
drwxr-xr-x. 2 root root 4096 May 18 16:03 games  
drwxrwx-T. 2 root gdm 4096 Jun 2 18:39 pdfs  
drwxr-xr-x. 38 root root 4096 May 18 16:03  
drwxr-xr-x. 2 root root 4096 May 18 16:03 log  
drwxr-xr-x. 2 root root 4096 May 18 16:03 private  
drwxr-xr-x. 2 root root 4096 Jul 1 22:11 repodata  
lrwxrwxrwx. 1 root root 6 May 14 00:12 run -> run  
drwxr-xr-x. 14 root root 4096 May 18 16:03 spool  
drwxrwxrwt. 4 root root 4096 Sep 12 23:58 tmp  
drwxr-xr-x. 2 root root 4096 May 18 16:03 yp  
[root@localhost var]# yum search wiki  
No matches found.  
[root@localhost var]# yum install mediawiki  
[root@localhost var]# rpm -q mediawiki  
mediawiki-1.32.0-1.el8.x86_64
```



VS

Start





Getting Git and for Windows Users - We Need Git Bash

Windows:

- <https://git-scm.com/download/win>

Mac (from Terminal)

```
1 # install homebrew
2 /bin/bash -c "$(curl -fsSL https://raw.githubusercontent.com/Homebrew/install/HEAD/
     install.sh)"
3
4 # might be necessary on M1/M2 Macs
5 eval $(/opt/homebrew/bin/brew shellenv)
6
7 # install git
8 brew install git
```

Linux (from Terminal)

```
1 sudo apt-get install git-all
```



Command Line Interface - Basic Navigation

The Command Line Interface (CLI) will allow us to directly navigate the computers operating system. We will use:

- macOS or Linux: Terminal
- Windows: PowerShell or Git Bash (we will use Git Bash)

The following commands will work on all three systems, except where noted below. macOS and Linux are case-sensitive, Windows is not.

- `pwd`: Show the present working directory.
- `ls`: To get the list of all the files or folders.
- `cd`: Used to change the directory.
- `du`: Show disk usage. (not available in PowerShell).
- `man`: Used to show the manual of any command.



Command Line Interface - File and Directory Manipulation

- **mkdir:** Used to create a directory if it does not already exist. It accepts directory name as input parameter.
- **rmdir:** Used to delete a directory if it is empty.
- **cp:** This command will copy the files and directories from source path to destination path. It can copy a file/directory with a new name to the destination path. It accepts source file/directory and destination file/directory.
- **mv:** Used to move files or directories. This command is similar to the cp command but it deletes a copy of the file or directory from the source path.
- **rm:** Used to remove files or directories.
- **touch:** Used to create or update a file. (PowerShell New-Item).



Command Line Interface - Displaying the file contents

- cat: It is generally used to concatenate files. It gives the output on the standard output.
- more: It is a filter for paging through text one screenful at a time.

The below commands are not available in PowerShell:

- less: Used for viewing files instead of opening the file. Similar to the "more" command but it allows backward as well as forward movement.
- head: Used to print the first N lines of a file. It accepts N as input and the default value of N is 10.
- tail: Used to print the last N-1 lines of a file. It accepts N as input and the default value of N is 10.

On all systems, commands can be "piped" together: ls | more <file>

GitHub - Part 1



Git and GitHub: Your Version Control Friends



Github



What is a version control system?

Version Control Systems (VCS) record changes made to files so that you can

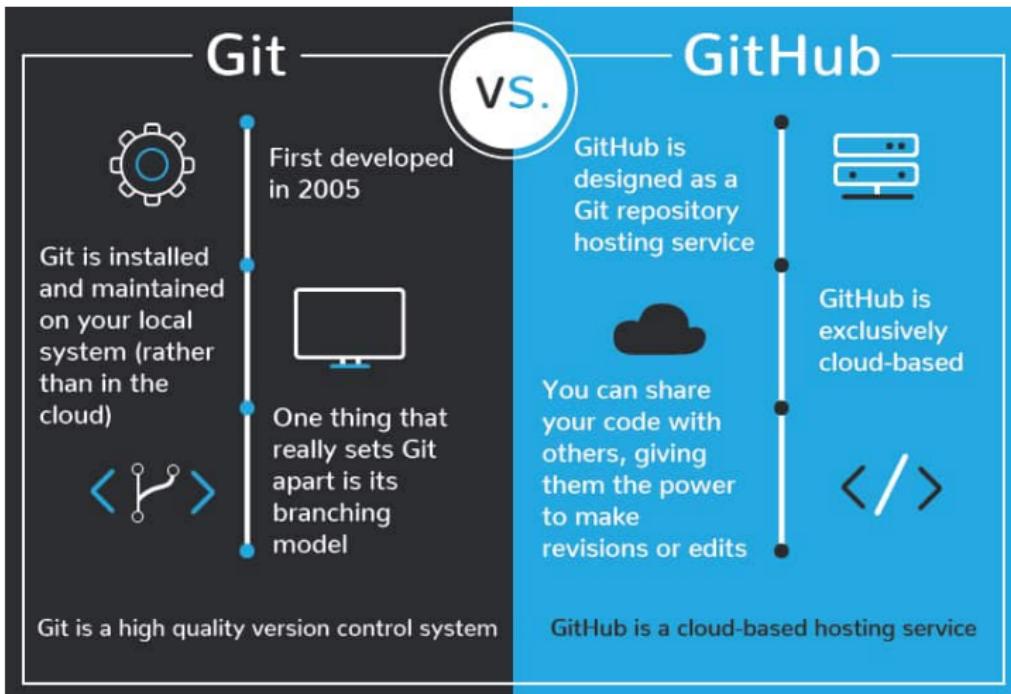
- compare and track changes over time
- revert single files to a previous state
- revert an entire project to an earlier version

Git is a VCS, or Version Control System.

It is similar to Backup on Windows or Time Machine on the Mac.



Git vs. GitHub





Commit vs. Push

To save files to your **LOCAL** repository, use the *commit* command. The file is given a timestamp and a unique commit number that is the file version.

→ git commit

To save a file to your **REMOTE** GitHub repository, use the *push* command.

→ git push

Remember to Push your files in order to save from data loss and to ensure your work is available for collaboration.



When should you commit and push your work?

When to commit? **OFTEN!**

- Any time you finish a task where you want to save or retain a version.

When to push? **OFTEN!**

- Any time you have finished a task, milestone, or significant project.
- At the end of each work session
 - Before you take a break
 - Before a meeting
 - Before lunch
 - Before you go offline for the day



Use Professional Naming



you named me
WHAT!?



Getting a GitHub account

If you do not already have a GitHub account, you will want to create one.

- ① Go to <https://github.com>
- ② Click Sign Up.
- ③ Type a unique username and password for your account.
 - *Note: you should consider a user name that is professional if you plan to share your GitHub account with prospective employers as part of your work portfolio.*
- ④ Complete the sign up process and Create Account.



GitHub Authentication: Using HTTPS and PAT

Effective August 2021, account passwords will no longer be allowed for command line GitHub access. Instead, you must create a Personal Access Token (PAT) to use in place of a less secure password.

To create a PAT:

- ① Login to your GitHub account.
- ② Click your account icon.
- ③ Click the Settings menu option.
- ④ Click Developer Settings.
- ⑤ Click Personal access tokens.
- ⑥ Generate a new token for GitHub Command Line Access.
- ⑦ Check the repo option.
- ⑧ Click Generate Token.

Now when you login to GitHub on the command line, use your PAT rather than your password to access your account.



GitHub: Cloning and Pulling Code

To get an existing GitHub repository, you will clone it to your local system.

git clone <URL of repository>

Let's get the Class Slide now, from your IoT directory:

```
1 git clone https://github.com/ddc-iot/class_materials
```

To get updates from a GitHub repository after you have already cloned it to your local system, you will pull the code.

git pull

Note: make sure you are in the repository folder before doing a git pull.



GitHub: Getting Assignments

ddc-iot-classroom-2

Accept the assignment —

L01_HelloWorld

Once you accept this assignment, you will be granted access to the `l01-helloworld-brashap` repository in the `ddc-iot` organization on GitHub.



You're ready to go!

You accepted the assignment, L01_HelloWorld.

Your assignment repository has been created:

<https://github.com/ddc-iot/l01-helloworld-brashap>

Accept this assignment

```
1 brian:~$ cd Documents/
2 brian:Documents$ mkdir IoT
3 brian:Documents$ cd IoT
4 brian:IoT$ git clone https://github.com/ddc-iot/L01_helloWorld-brashap
5 Cloning into 'L01_helloWorld'...
6 Username for 'https://github.com': brashap
7 Password for 'https://brashap@github.com':
8 remote: Enumerating objects: 4, done.
9 remote: Counting objects: 100% (4/4), done.
10 remote: Compressing objects: 100% (3/3), done.
11 remote: Total 4 (delta 0), reused 4 (delta 0), pack-reused 0
12 Unpacking objects: 100% (4/4), 321 bytes | 53.00 KiB/s, done.
```



GitHub: Cheatsheet. Memorize this!

```
1 // In GitBash or Terminal go to ./Documents/IoT
2 // Get a repository that already exists and pull
   it into your local machine
3 git clone <URL of repository>
4
5 // Send your changes up to the repository
6 git add . //adds all changed files
7 git commit -m "some comment"
8 git push //send your changes to the cloud
9
10 // The first time you use git, you may get asked
    to enter your GIT username
11 git config --global user.email "you@example.com"
12
13 // From the repository directory , get updates
14 git pull
```



A word about Open Source Licenses

Type	Permissive	Permissive	Permissive	Copyleft	Copyleft	Copyleft
Provides copyright protection	✓ TRUE	✓ TRUE	✓ TRUE	✓ TRUE	✓ TRUE	✓ TRUE
Can be used in commercial applications	✓ TRUE	✓ TRUE	✓ TRUE	✓ TRUE	✓ TRUE	✓ TRUE
Provides an explicit patent license	✓ TRUE	✗ FALSE	✗ FALSE	✗ FALSE	✗ FALSE	✗ FALSE
Can be used in proprietary (closed source) projects	✓ TRUE	✓ TRUE	✓ TRUE	✗ FALSE	✗ FALSE partially	✗ FALSE for web
Popular open-source and free projects	Kubernetes Swift Firebase	Django React Flutter	Angular.js jQuery .NET Core Laravel	Joomla Notepad++ MySQL	Qt SharpDevelop	SugarCRM Launchpad

- Copyleft require the publication of the source code of any modified versions under the original work's copyleft license.
- Permissive does not guarantee that modified versions of the software will remain free and publicly available, generally requiring only that the original copyright notice be retained.



Solidworks - Windows Users

To install Solidworks (Windows only), go to

<http://www.SolidWorks.com/SEK>

- Enter your contact information.
- Check the radio button “Yes” under ”I already have a Serial Number that starts with 9020”.
- Select the version: 2024 SP5.0 and click Request Download.
- On the next page, Accept the agreement and continue.
- On the final page, click the Download button to download the SolidWorks Installation Manager.
- Unzip the files to launch the Installation.
- Select the option for Individual/On this machine.
- Install using the following serial number provided by your instructor.

macOS and Linux users will use onShape:

<https://www.onshape.com/en/education/>



Other Software

① Fritzing

- Installer is in Brightspace: Module 02 HelloLED

② Bambu Studio

- <https://bambulab.com/en/download/studio>

③ Adobe Illustrator

- <https://www.adobe.com/creativecloud.html>

④ KiCad

- <https://www.kicad.org/download/>

⑤ Drawio

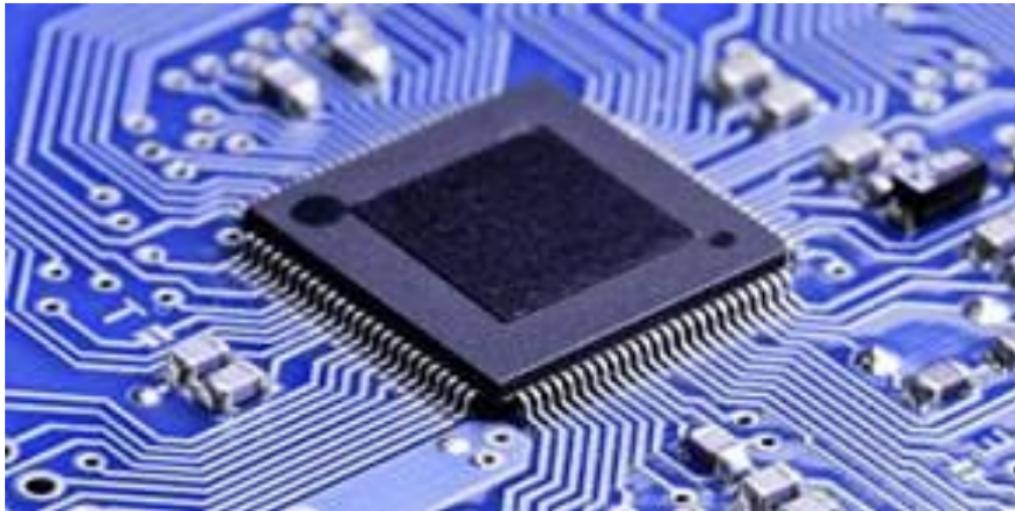
- <https://app.diagrams.net/>

⑥ Bookmark: <https://www.desmos.com/>

Particle Photon2

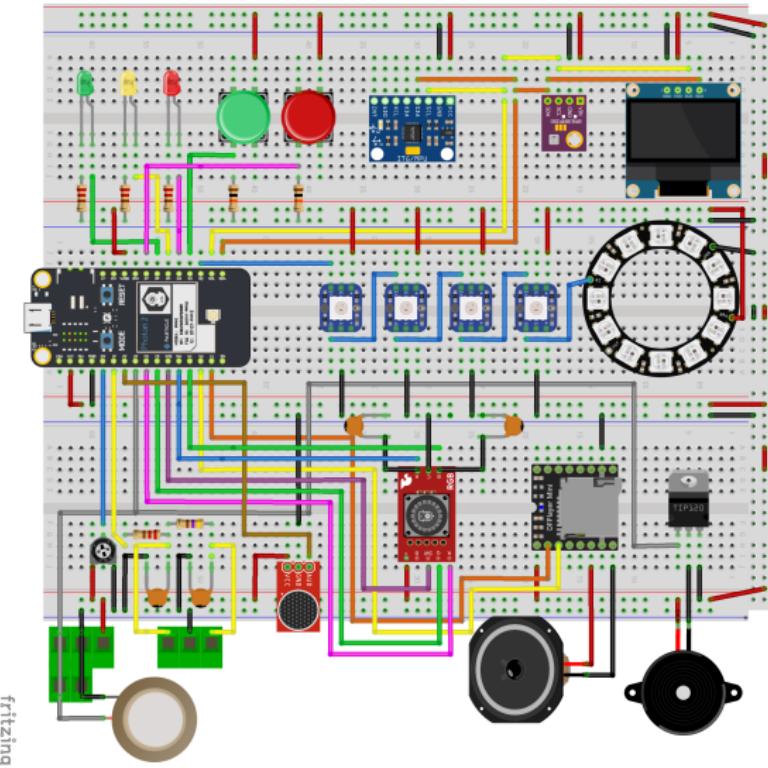


Our Microcontroller



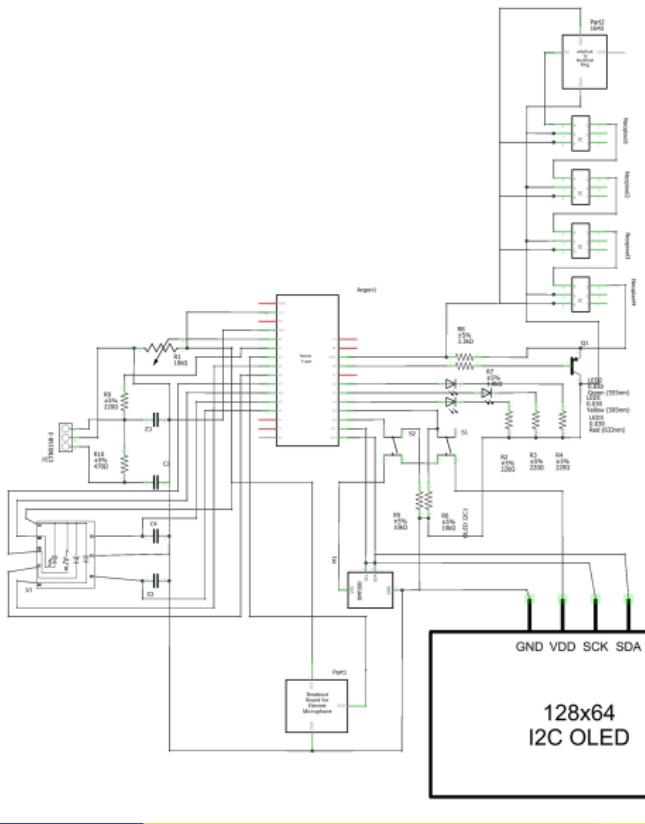


Smart Room Controller





Smart Room Controller Schematic





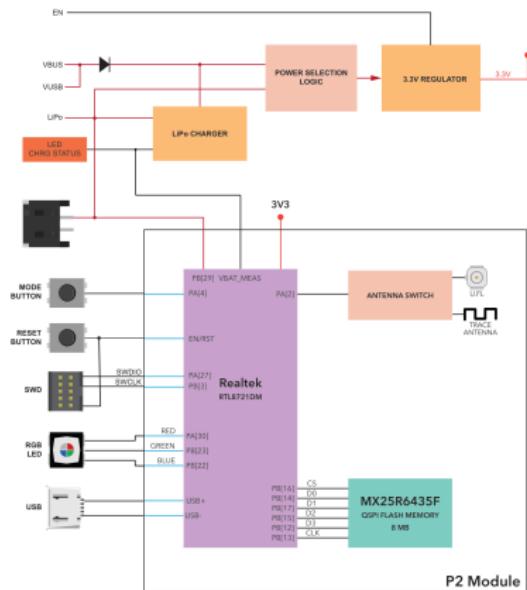
Particle Photon2



Peripheral Type	Qty	Input(I) / Output(O)
Digital	20	I/O
Analog (ADC)	6	I
SPI	2	I/O
I2C	1	I/O
UART	3	I/O
USB	1	I/O
PWM	5	O



Particle Photon2 Block Diagram

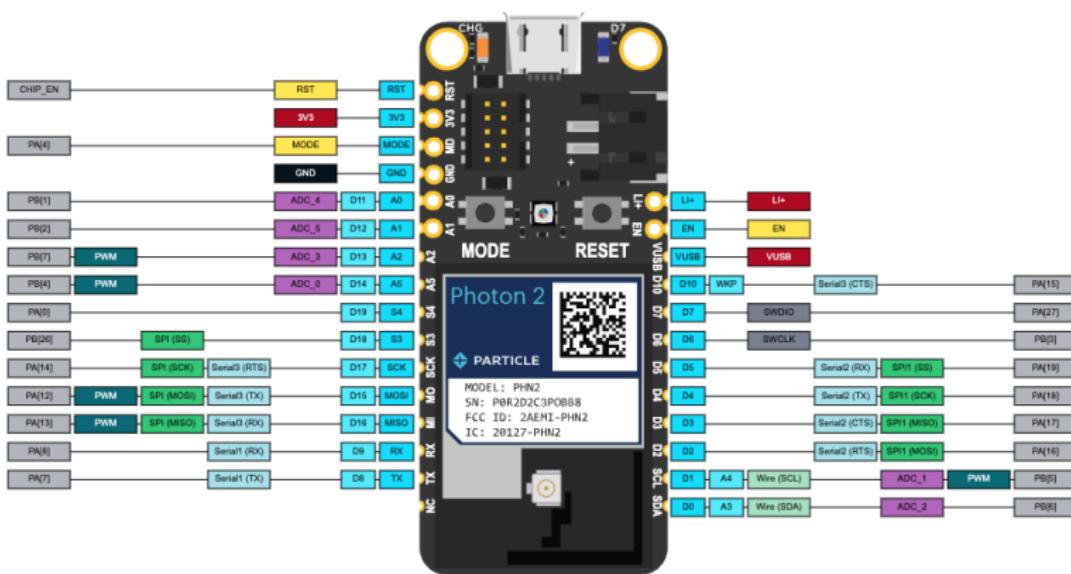


Features

- 802.11a/b/g/n Wi-Fi, 2.4 GHz and 5 GHz
 - Integrated PCB antenna
 - Integrated U.FL connector for external antenna
 - Integrated RF switch
- BLE 5 using same antenna as Wi-Fi
- Realtek RTL8721DM MCU
 - ARM Cortex M33 CPU, 200 MHz
- 2048 KB (2 MB) user application maximum size
- 3072 KB (3 MB) of RAM available to user applications
- 2 MB flash file system
- FCC, IC, and CE certified



Photon2 Pinout





Particle Cousins



You may see the Particle Argon on some wiring diagrams in later slides. In those cases, the Argon and the Photon2 are fully interchangeable.



Particle Next Generation



The Muon, Particle's new multi-radio device designed to simplify and revolutionize connectivity. It combines a full suite of popular radios—built into the M-SoM are cellular, Wi-Fi, BLE, GNSS, NTN satellite, and then the Muon brings LoRaWAN and Ethernet.

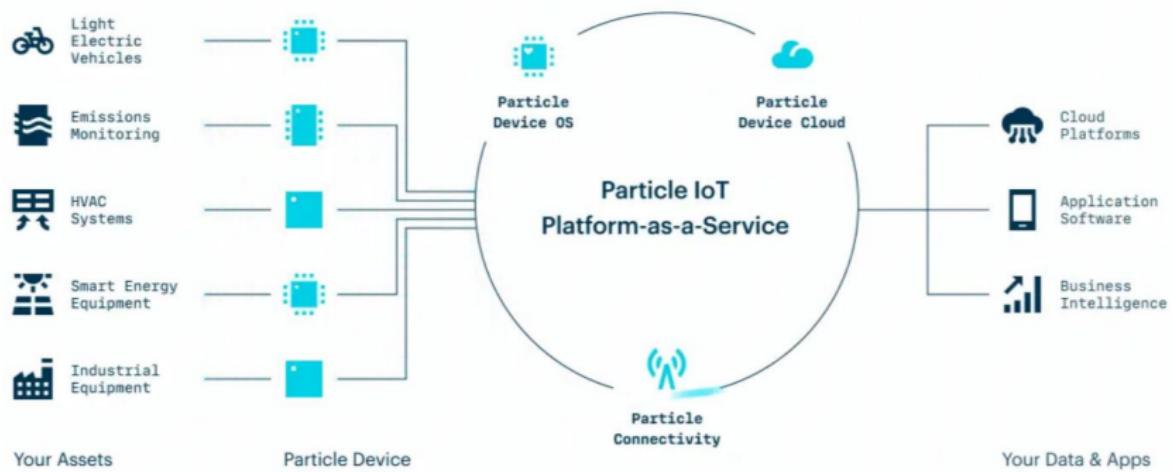
You may see the Particle Argon on some wiring diagrams in later slides. In those cases, the Argon and the Photon2 are fully interchangeable.



Tachyon is a 5G-connected single-board computer (SBC) that takes the technology inside a modern smartphone and packs it into a Raspberry Pi form factor. This has a powerful Qualcomm Dragonwing SoC, an AI accelerator, and Particle's application infrastructure,

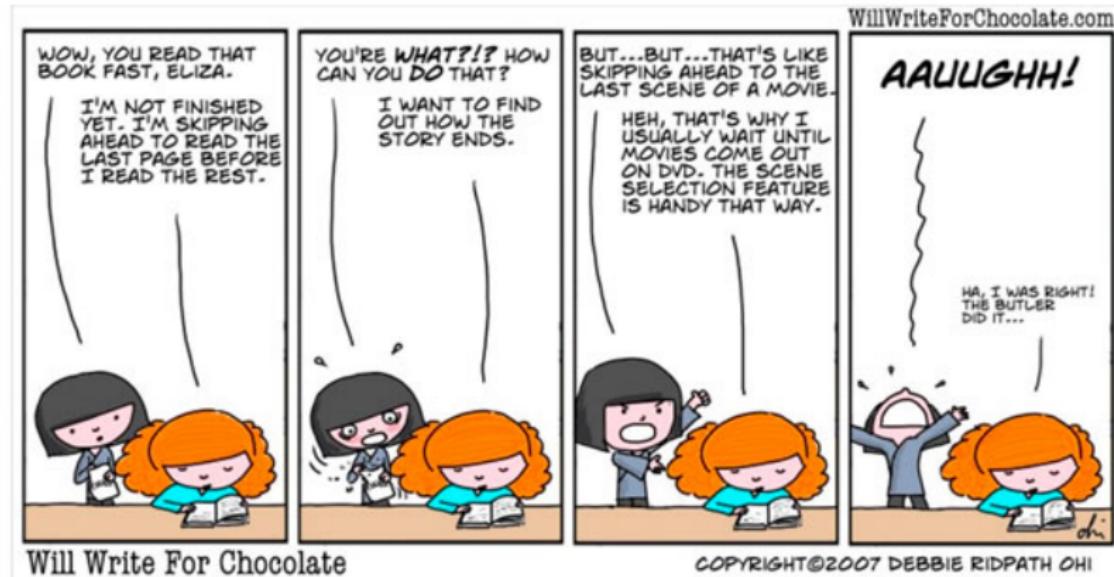


Platform as a Service





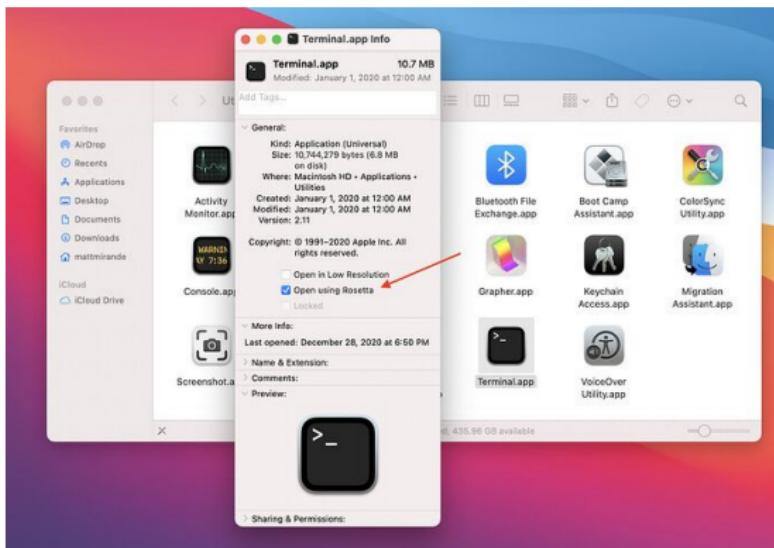
Please Do Not Skip Ahead During Setup





If you have a Mac M1/M2 (Apple Silicon)

Terminal needs to be “Open using Rosetta” option:



<https://www.courier.com/blog/tips-and-tricks-to-setup-your-apple-m1-for-development/>



Installing Particle CLI

Windows (After download, right click and Run as Administrator):

- <https://docs.particle.io/tutorials/developer-tools/cli/>

Mac

```
1 # install the CLI
2 bash < curl -sL https://particle.io/install-cli )
3
4 # install the DFU-util, a utility program for programming devices over USB
5 brew install dfu-util
6
7 # either or both of the following might be necessary on M1/M2 Macs
8 eval $(/opt/homebrew/bin/brew shellenv)      # if brew doesn't work
9 arch -arm64 brew install dfu-util            # if architecture error
```

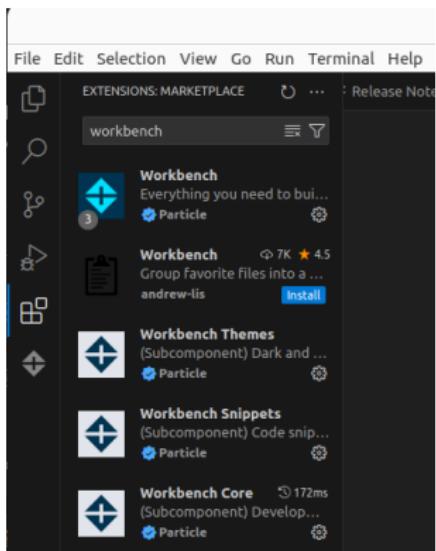
Linux

```
1 # install the CLI
2 bash < curl -sL https://particle.io/install-cli )
3
4 # install the DFU-util, a utility program for programming devices over USB
5 sudo apt-get install dfu-util
```

- Test that the Particle CLI installed correctly by going to GitBash or Terminal and type particle.



Particle Software - Visual Studio Code

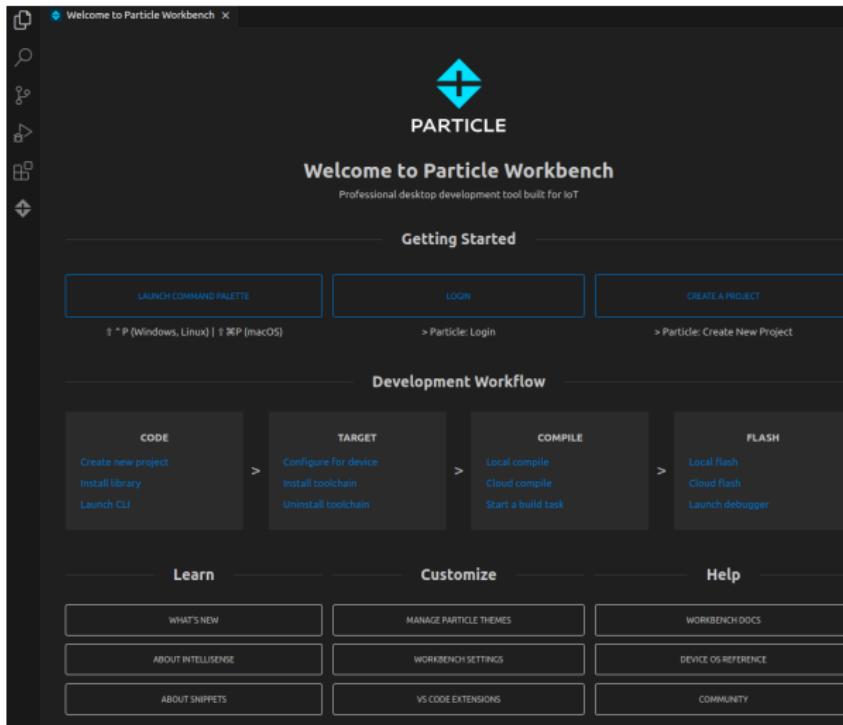


- ➊ Create Particle login:
<https://login.particle.io/signup>
- ➋ Install VSCode: <https://code.visualstudio.com/download>
- ➌ Install the Particle Workbench extension



Particle Workbench - VSCode Configuration

Select Customize → Workbench Settings:





Particle Workbench - VSCode Configuration

A screenshot of the Particle Workbench configuration interface within the VSCode extension. The interface is dark-themed and displays several configuration sections:

- Particle: Enable Pre-release Device OSBuilds**: A checkbox labeled "Show pre-release OS firmware builds as build targets. Please refrain from selecting firmware labeled as pre-release for your projects without consulting particle.enablePre-releaseDeviceOSBuilds".
- Particle: Enable Verbose Local Compiler Logging**: A checkbox labeled "Show all local compiler build logs".
- Particle: Firmware Name**: A dropdown menu set to "deviceOS".
- Particle: Firmware Version**: A dropdown menu set to "5.8.0".
- Particle: Flash Button Action**: A dropdown menu set to "localAppDeviceOS".
- Particle: Max Allowed Toolchains**: A numeric input field set to "4".
- Particle: Target Device**: A dropdown menu showing a partially visible device name.
- Particle: Target Platform**: A dropdown menu set to "p2".

- Enable Pre-Release
- Firmware Version set to version indicated by Instructor.
- Target Platform to P2



Particle Setup

- ① Plug the Photon2 into a USB port. It should begin blinking blue.
- ② Open GitBash or Terminal.
- ③ Login into your Particle Account.

```
1 particle login
```

- ④ Ensure you have the latest Particle CLI.

```
1 particle update-cli
```

- ⑤ Setup WiFi using <https://docs.particle.io/tools/developer-tools/configure-wi-fi/>
- ⑥ Put the Photon2 in DFU mode (blinking yellow) by holding down MODE. Tap RESET and continue to hold down MODE. The status LED will blink magenta (red and blue at the same time), then yellow. Release when it is blinking yellow.



Updating your Photon2 to latest Device OS

- ① Update the device by running the following two commands. If the device goes out of blinking yellow after the first command, put it back into DFU mode. See Note ⁴.

```
1 particle update  
2 particle flash --usb tinker
```

- ② Verify that the update worked by running the following command:

```
1 particle serial identify  
2  
3 Your device id is e00fce681ffffffffc08949b  
4 Your system firmware version is 1.5.2
```

⁴particle flash –usb tinker can be used for device troubleshooting



Claim Your Device

- ① Claim the device to your account. This can only be done if it's breathing cyan. Replace e00fce681fffffffffc08949b with the device ID you got earlier from particle serial identify. Then, rename it to the name of your choice.

```
1 particle device add e00fce681fffffffffc08949b  
2 particle device rename e00fce681fffffffffc08949b myPhoton2
```

- ② Ensure that your setup flag is marked as done.

```
1 particle usb setup-done
```

- ③ You have successfully set up your Photon2!



Useful Particle CLI Commands

- ① Enter DFU mode from the CLI.

```
1 particle usb dfu
```

- ② If the Particle won't enter DFU mode or is otherwise acting strangely, restore the base firmware.

```
1 particle flash --usb tinker
```

- ③ Get a list of your Particle devices and their connection status.

```
1 particle list
```

- ④ Search for available libraries.

```
1 particle library search <search term>
```

- ⑤ Link for the Particle Setup procedures: [Particle Setup via CLI](#)



Particle LED Modes

Mode	LED Status
Connected	Breathing Cyan
OTA Firmware Update	Blinking Magenta (red and blue together)
Looking for Internet	Blinking Green
Connecting to Cloud	Rapid Blinking Cyan
Listening Mode	Blinking Blue
Network Reset	Rapid Blinking Blue
WiFi Off	Breathing White
Safe Mode	Breathing Magenta (red and blue together)
DFU (Device Firmware Upgrade)	Blinking Yellow
Restore Factory Firmware	Rapid Blinking Yellow
Factory Reset	Rapid Blinking White
Decryption Error	Blinking Cyan followed by 1 Orange Blink
No Internet	Blinking Cyan followed by 2 Orange Blink
No Particle Cloud	Blinking Cyan followed by 3 Orange Blink
Authentication Error	Blinking Cyan followed by 1 Magenta Blink
Handshake Error	Blinking Cyan followed by 1 Red Blink
Decryption Error	Blinking Cyan followed by 1 Orange Blink
SOS - Firmware Crash	Blinking Red - 3 short, 3 long, 3 short, error code



Improve Compile Time

Anti-virus programs scan everything that VSCode is doing. This leads to long compile times. To reduce the compile times, you can exclude your particle code from real-time virus scans.

Manage exceptions

Add or remove items to be excepted from scan.

+ Add an Exception

All exceptions Antivirus Advanced Threat Defense

c:\users\ddcio\particle
On-access, On-demand, Embedded scripts

c:\users\ddcio\vscode
On-access, On-demand, Embedded scripts

c:\users\ddcio\documents\iot
On-access, On-demand, Embedded scripts



Go to Start > Settings > Update & Security > Windows Security > Virus & threat protection. Under Virus & threat protection settings, select Manage settings, and then under Exclusions, select Add or remove exclusions. Select Add an exclusion, and then select from files, folders, file types, or process.



How to exclude files and folders from Bitdefender Antivirus scan

1. Click Protection on the navigation menu on the Bitdefender interface.
2. In the ANTIVIRUS pane, click Open.
3. In the Settings window, click Manage Exceptions.
4. Click +Add an Exception.



To set a global exception:

1. Open AVG AntiVirus and go to ⌂ Menu ▶ Settings.
2. Select General ▶ Exceptions, then click Add exception.
3. Add an exception in one of the following ways: Type the specific file/folder path or URL into the text box, then click Add exception.



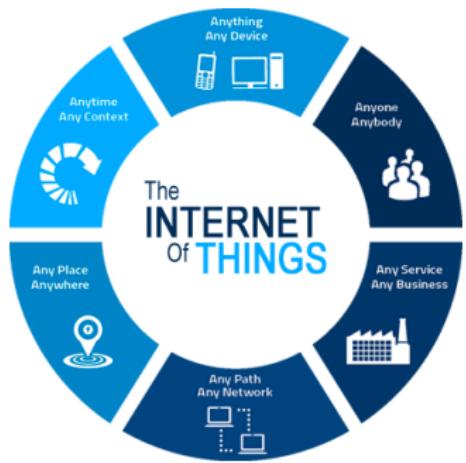
1. Open your McAfee security software.
2. Click PC Security.
3. Click Real-Time Scanning.
4. Click Excluded Files.
5. Click Add file.
6. Browse to, and select, the file that you want to exclude from Real-Time scanning.



Module 1 - HelloWorld



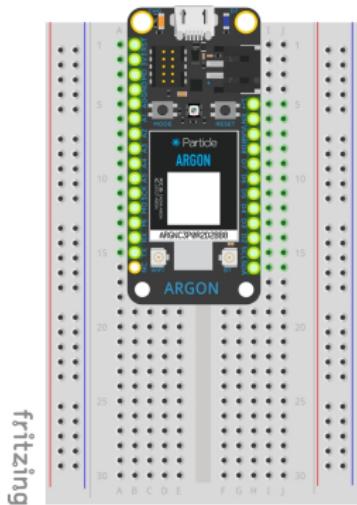
Module 1 Objectives



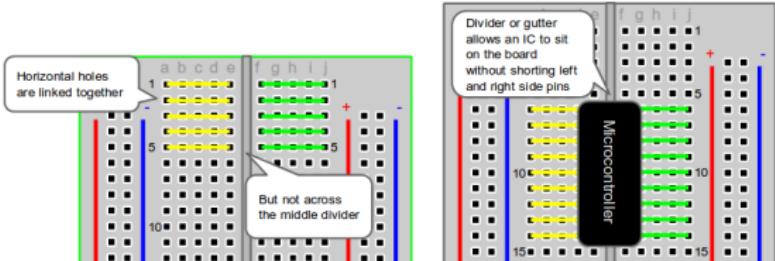
- Learning Objectives
 - ➊ Your First Program
- Additional Items
 - ➋ 3D Modeling Lesson 0 - Getting Started



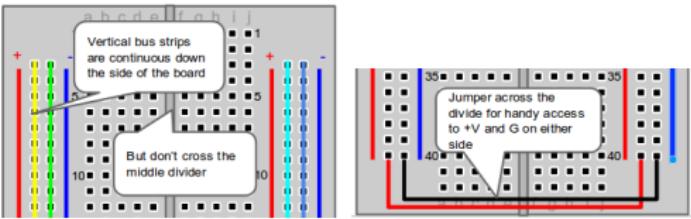
Argon or Photon 2 on Breadboard



Horizontal Rows



Vertical Columns





Basic Structure of IoT Program

```
1 // the "header" is used for GLOBALS
2
3 void setup() {
4     // code in setup() runs once
5     // it is used to initialize objects,
6     // begin processes, and set variables
7     pinMode(D7, OUTPUT); //set Pin D7 as an Output
8 }
9
10 void loop() {
11     // functionality of your code
12     // this loops indefinitely
13 }
```



Class Assignments

- ① Lab Notebook - flow chart
- ② Lab Notebook - schematic
- ③ Fritzing breadboard layout
- ④ IoT code with comments

```
1 /*
2  * Project:      Title of Project
3  * Description: Description of Project
4  * Author:       Your Name
5  * Date:        Today's Date
6 */
7
8 // Single Line Comments
```



Hello World in some of the 603+ Coding Languages

Fortran

```
c      Hello world in Fortran
      PROGRAM HELLO
      WRITE (*,100)
      STOP
100 FORMAT (' Hello world! ' /)
      END
```

C (K&R)

```
/* Hello world in c, K&R-style */
main()
{
    puts("Hello world!");
    return 0;
}
```

Python 2

```
# Hello world in python_2
print "Hello world"
```

Assembler (Intel)

```
; Hello world for intel Assembler (MSDOS)
mov ax,cs
mov ds,ax
mov ah,9
mov dx, offset Hello
int 21h
xor ax,ax
int 21h
```

```
Hello:
db "Hello world!",13,10,"$"
```

Powershell

```
# Hello World in Microsoft Powershell
'Hello world!'
```

LabVIEW

Hello world in LabVIEW 7.1
Hello World!

LaTeX

```
% Hello world! in LaTeX
\documentclass{article}
\begin{document}
Hello world!
\end{document}
```

Unix Shell

```
# Hello world for the unix_shells (sh, ksh, csh, zsh, bash, fish, xonsh, ...)
echo Hello world
```

Lisp-Emacs

```
(defun hello-world()
  "Display the string hello world."
  (interactive)
  (message "hello world"))
```

BASIC

```
10 REM Hello world in BASIC
20 PRINT "Hello world!"
```

C++

```
// Hello world in C++ (pre-ISO)
#include <iostream.h>
main()
{
    cout << "Hello world!" << endl;
    return 0;
}
```

Perl

```
# Hello world in perl
print "Hello world!\n";
```

Python 3

```
# Hello world in Python_3
print("Hello world")
```

Pascal

```
{Hello world in pascal}
program Helloworld(output);
begin
    writeln('Hello world!');
end.
```

MATLAB

```
% Hello world in MATLAB.
disp('Hello world');
```

HTML

```
<HTML>
<!-- Hello world in HTML -->
<HEAD>
<TITLE>Hello world!</TITLE>
</HEAD>
<BODY>
Hello world!
</BODY>
</HTML>
```

Postscript

```
% Hello World in Postscript
%PS
/Palatino-Roman findfont
100 scalefont
setfont
100 100 moveto
(Hello world!) show
showpage
```



Assignment L01_01_HelloWorld



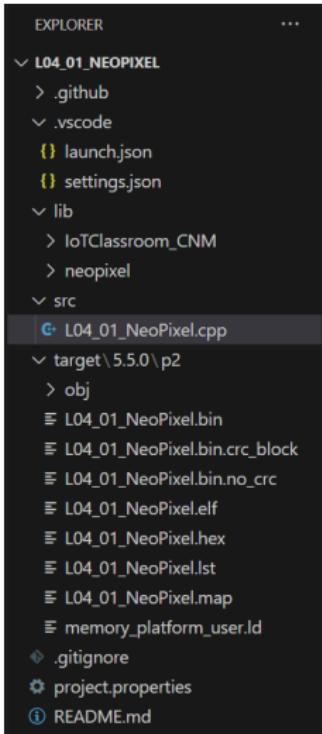
We will write our first program together as a class, using:

- `pinMode(pin,mode)`
- `digitalWrite(pin,state)`
- `delay(delay_time)`

How fast can you make it blink and still see it blinking?



Directory Structure - VERY IMPORTANT

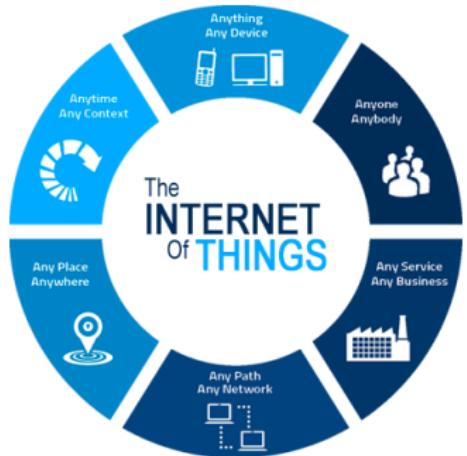


- The .vscode directory contains the project-specific settings.
- The src directory contains the source (.cpp) file.
 - Matches the project (main directory name)
 - Is referenced in other parts of the directory.
 - Caution: this is one reason Save-As doesn't work.
- The lib directory contains the source to libraries that have been included. More on this in Lesson 4.
- The target directory contains local build output (the machine code for the particle)
- The project.properties file specifies all of the libraries that this project uses.
- README.md contains documentation for the project.

Module 2 - HelloLED



Module 2 Objectives



- Learning Objectives

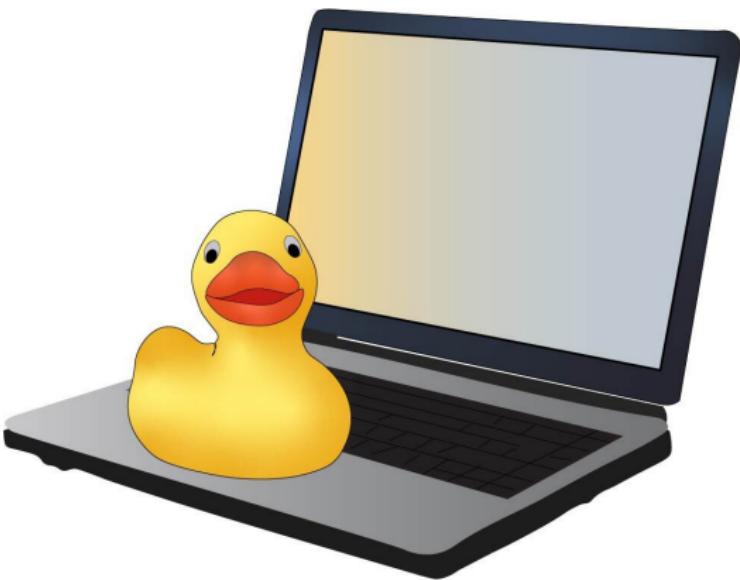
- 1 Basic Electrical Circuits - Resistors and Diodes
- 2 Using a Multimeter
- 3 Constants and Variables
- 4 Digital and Analog Outputs
- 5 For and While Loops
- 6 Counting in Binary

- Additional Items

- 1 Wood or Metal shop
- 2 Fritzing
- 3 Quiz 1



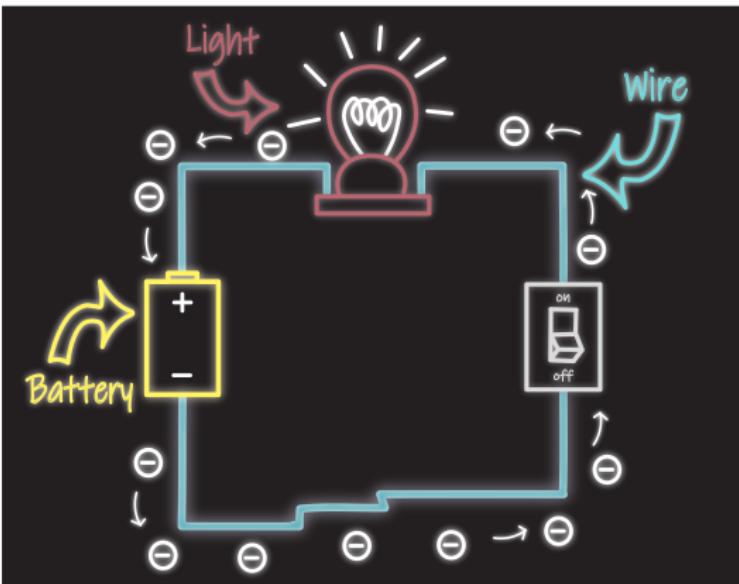
Rubber Ducking - An Odd but Brilliant Tool



Rubber ducking is simply a method of debugging code. Programmers carry around a rubber duck with them, When they get stuck, they explain their code line-by-line to the rubber duck.

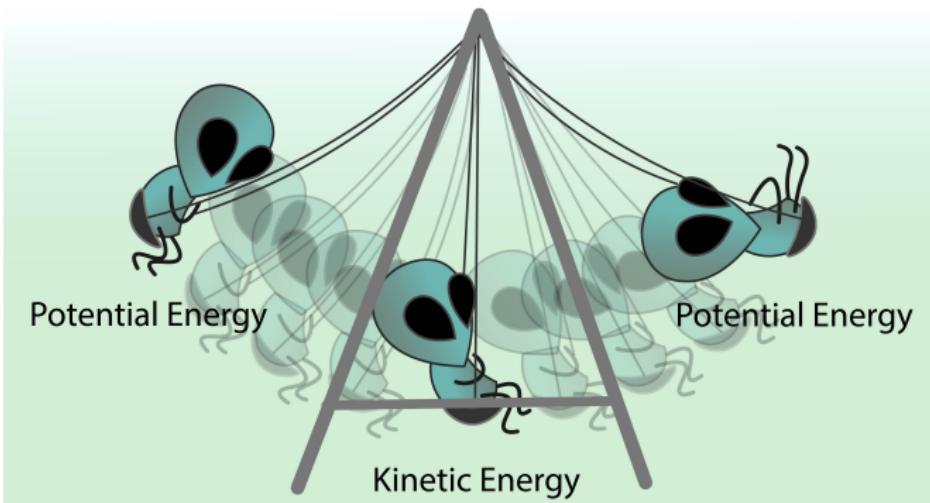


Introduction to Electrical Circuits





Energy



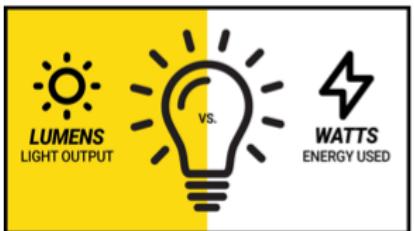
- Kinetic Energy - energy of motion
- Potential Energy - energy stored in an object



Electrical Circuit Terms

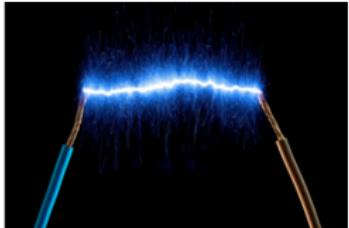


Voltage is **electric potential energy per unit charge** ($V = J/C$)

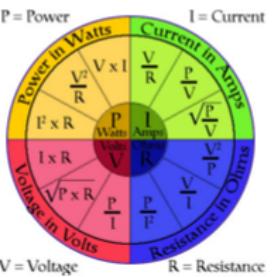


Power is the rate of doing work or **the rate of using energy**. ($W = J/S$)

The Sub-atomic Particles			
Relative size	Name	Mass (Kg)	Charge (C)
Proton	Proton	1.67×10^{-27}	$+1.602 \times 10^{-19}$
Neutron	Neutron	1.67×10^{-27}	0
Electron	Electron	9.11×10^{-31}	-1.602×10^{-19}



Electric current is the **rate of charge flow** ($A = C/s$)



$$\text{Power} = \text{Voltage} \times \text{Current}$$



Energy is the **amount of power produced or consumed over a given time**. ($J = W \times s$)

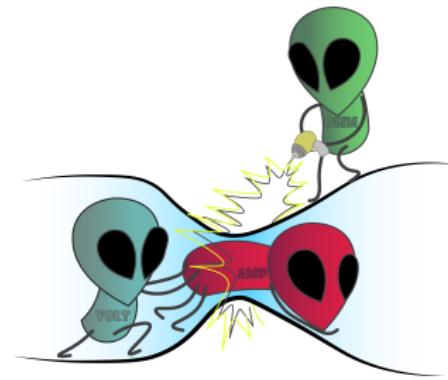
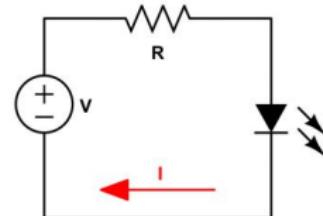


Ohm's Law

Georg Ohm (16 March 1789 – 6 July 1854) was a German physicist and mathematician. As a school teacher, Ohm began his research with the new electrochemical cell, invented by Italian scientist Alessandro Volta. Ohm found that there is a direct proportionality between the potential difference (voltage) applied across a conductor and the resultant electric current. This relationship is known as Ohm's law:

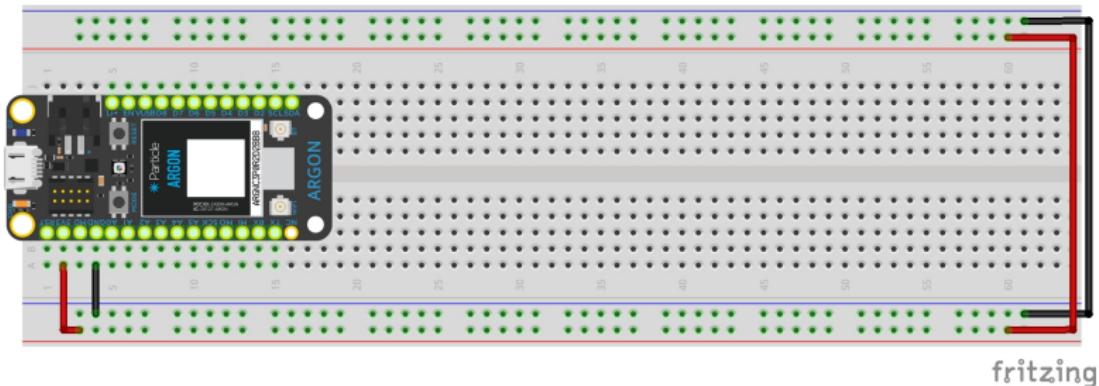
Ohm's Law

$$V = I * R$$





Power from the Particle

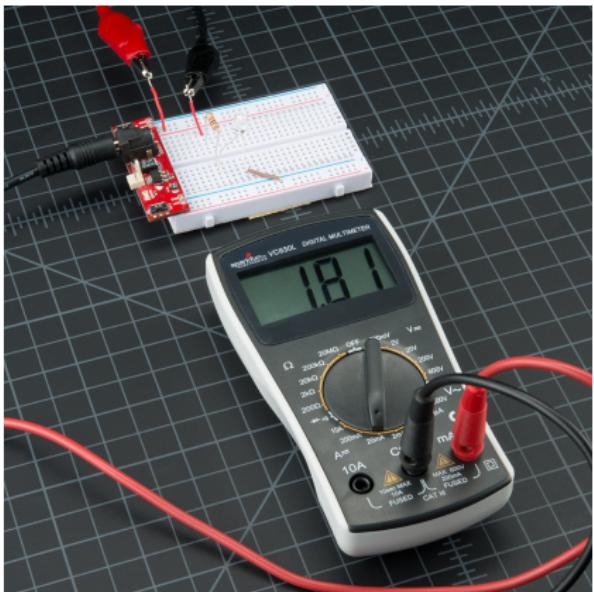


The Particle device has three pins related to power:

- 3.3V: 500mA of power to be used for most hardware
- V_{USB} : 5V from the USB cable to power 5V hardware
- GND: The ground pin to close the electrical loop

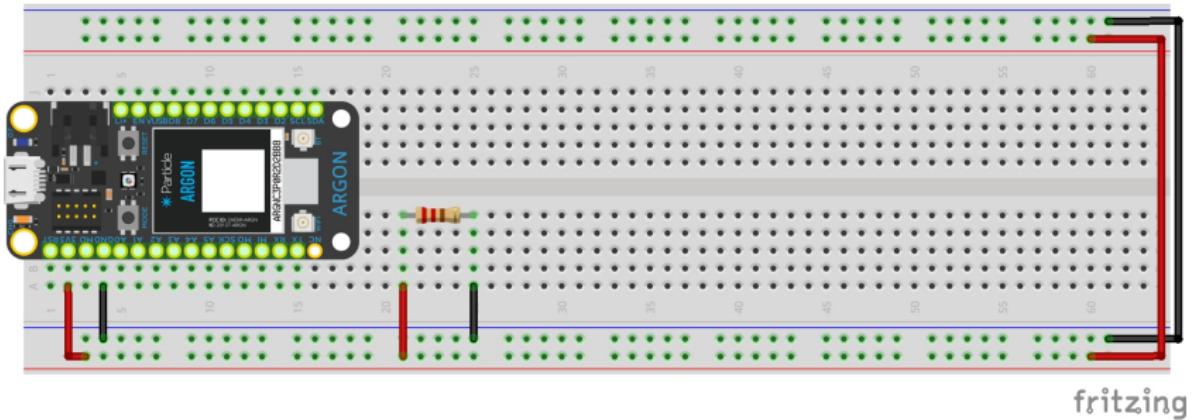


Measuring Voltage, Current, and Resistance





One Resistor



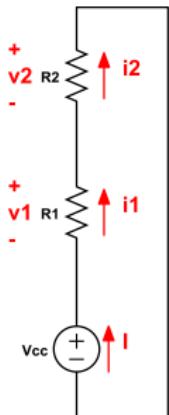
fritzing

Using your multimeter, measure the voltage "across" and current "through" the resistor.



A word about circuit notation

Subscripts will be used to denote quantities (voltage, current, etc) for different elements:



- i_1 or i_1 is the current through Resistor 1 (R_1)
- i_2 or i_2 is the current through Resistor 2 (R_2)
- v_2 or v_2 is the voltage across Resistor 2 (R_2)
- I is the current delivered by the power supply
- V_{cc} (common collector ^a voltage) is the notation we will use for 3.3V from the Particle

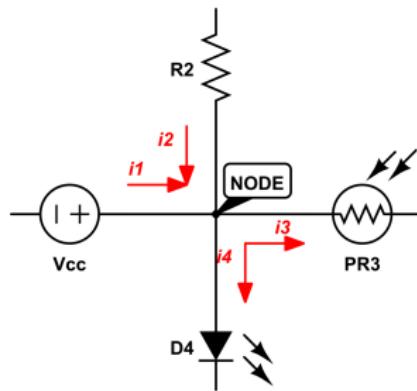
^aCommon Collector is a term for certain parts of transistor circuits. We will learn about Transistors in Lesson 11



Kirchhoff's First Law

Gustav Robert Kirchhoff (12 March 1824 – 17 October 1887) was a German physicist who contributed to the fundamental understanding of electrical circuits. His first law:

In an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node

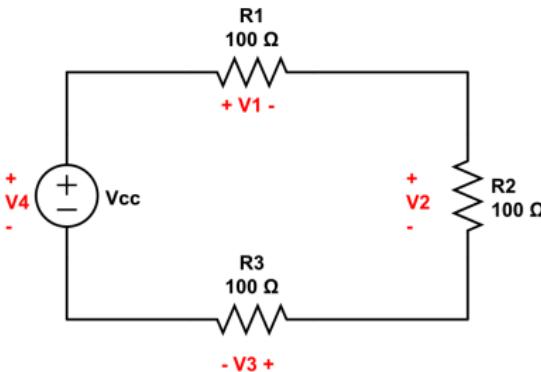


$$i_1 + i_2 = i_3 + i_4$$



Kirchhoff's Second Law

The directed sum of the potential differences (voltages) around any closed loop is zero.



$$V4 - (V1 + V2 + V3) = 0$$

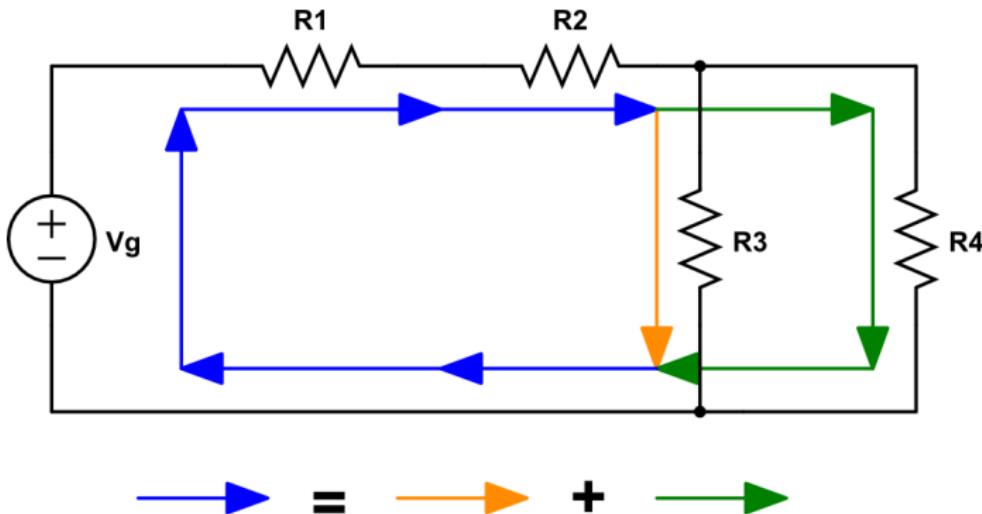


Kirchhoff's Second Law





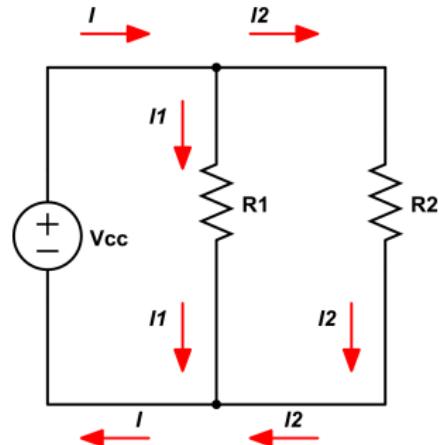
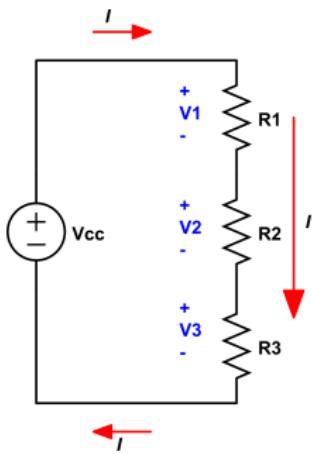
Resistors in Series and Parallel



How many nodes? How many loops?



Resistors in Series and Parallel

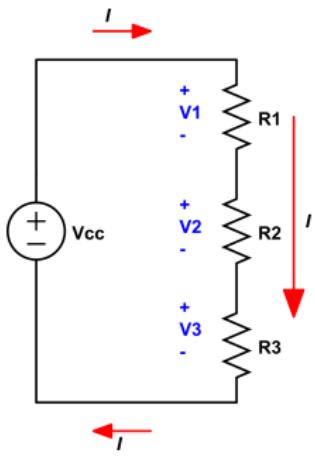


$$R_{eq} = R_1 + R_2 + R_3$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$



Resistors in Series



Node Law: $I = I_1 = I_2 = I_3$

Loop Law:

$$V_{cc} - (V_1 + V_2 + V_3) = 0$$

Rearranging the Loop Law:

$$V_{cc} = V_1 + V_2 + V_3 \quad (1)$$

Using Ohm's Law:

$$V_{cc} = IR_1 + IR_2 + IR_3 \quad (2)$$

Using the Distributive Property:

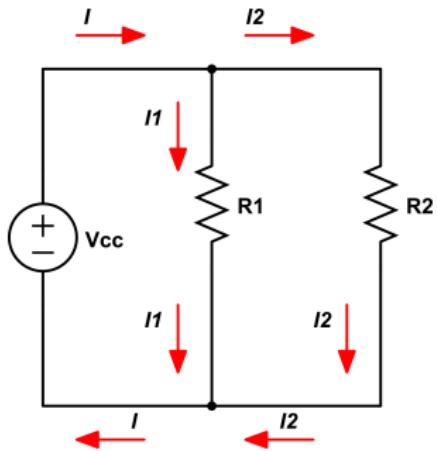
$$V_{cc} = I(R_1 + R_2 + R_3) \quad (3)$$

Gives the Equivalent Resistance:

$$R_{eq} = R_1 + R_2 + R_3 \quad (4)$$



Resistors in Parallel



$$I = I_1 + I_2 \quad (5)$$

$$I = \frac{V_1}{R_1} + \frac{V_2}{R_2} \quad (6)$$

$$I = \frac{V_{cc}}{R_1} + \frac{V_{cc}}{R_2} \quad (7)$$

$$\frac{V_{cc}}{R_{eq}} = V_{cc} \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \quad (8)$$

Node Law: $I = I_1 + I_2$

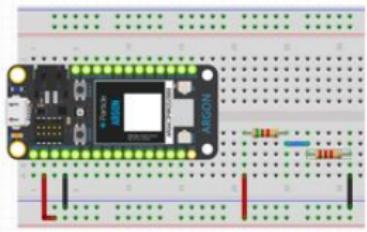
Loop Law: $V_{cc} = V_1 = V_2$

$$\frac{1}{R_{eq}} = \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \quad (9)$$

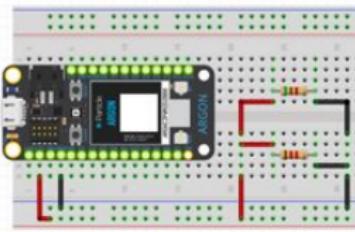


Assignment: L02_00_Resistors

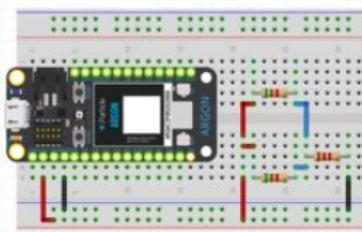
Series



Parallel



Combined

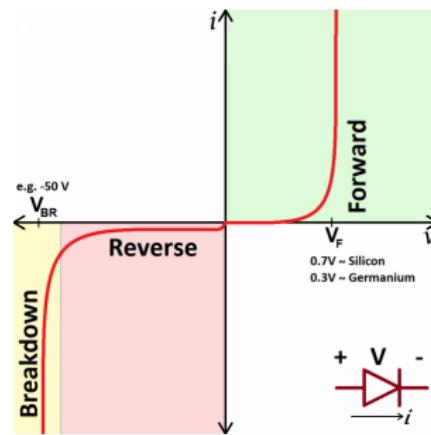


- In your lab notebook, draw the circuit diagrams
 - ① Series: $5.1\text{k}\Omega$ and $1.2\text{k}\Omega$
 - ② Parallel: $5.1\text{k}\Omega$ and $1.2\text{k}\Omega$
 - ③ Combined: Two parallel $5.1\text{k}\Omega$ in series with $1.2\text{k}\Omega$
- Calculate the combined resistance, the voltage at each node, and the current through each component.
- Create Fritzing diagram.
- Build (**one at a time**) on your breadboard and test your calculations with a multimeter.



Diodes

The key function of a diode is to control the direction of current-flow. Current passing through a diode can only go in one direction, called the forward direction. Current trying to flow the reverse direction is blocked.

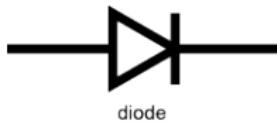


A non-ideal diode needs a small forward voltage (V_F) to turn on and will fail (breakdown) with a large negative voltage (V_{BR}).



Light Emitting Diodes

LEDs (that's "ell-ee-dees") are a particular type of diode that convert electrical energy into light.



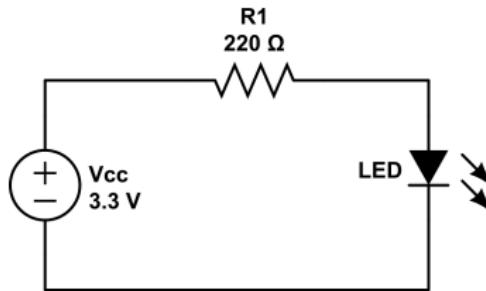


Current Limiting Resistors

As an LED has very little resistance, when it is connected directly to a power supply, the current draw will exceed its specifications and it will burn out.

$$V_{cc} - V_{LED} = IR \implies R >= \frac{V_{cc} - V_{LED}}{I_{max}}$$

For a 3.3V power supply, a 0.43V across the LED, and a max current of 100mA, the resistor needs to be greater than 29Ω .





SYSTEM_MODE and SYSTEM_THREAD

SYSTEM_MODE controls how the device connects with the cloud. By default, the device connects to the Cloud and processes messages automatically. However there are many cases where a user will want to take control over that connection. There are three available modes:

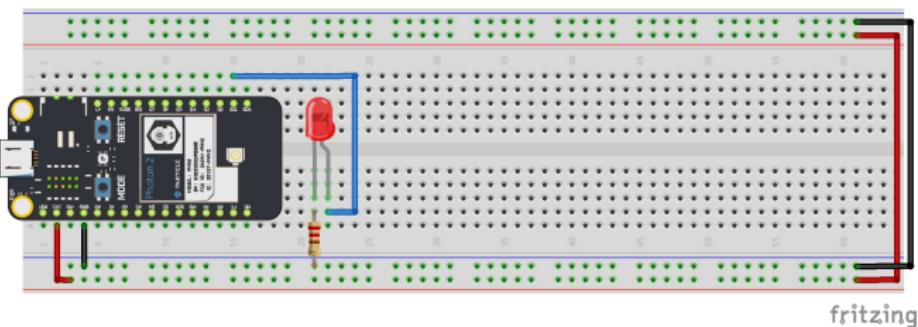
- AUTOMATIC: connect to WiFi and Particle Cloud
- SEMI_AUTOMATIC: start with WiFi off, once connected automatically handles reconnection
- MANUAL: WiFi off, connect and reconnect manual

```
1 //The below is placed in the header before Void Setup()
2
3
4 // SYSTEM_MODE(AUTOMATIC);      // Default if no SYSTEM_MODE included
5 // SYSTEM_MODE(SEMI_AUTOMATIC); // Uncomment if using without Wifi
6 // SYSTEM_MODE(MANUAL);        // Fully Manual
```

SYSTEM_THREAD creates a separate process to handle the internet connection. It is disabled by default and should be kept disabled for those first learning the Particle ecosystem.



Assignment L02_01_helloLED



- Using Pin D1 as an output and a 220Ω current limiting resistor, blink the LED once per second.
- Change the resistor to $1k\Omega$ and then $10k\Omega$. What happens to the brightness?
- Extra: Measure the current in each case. Record in your notebook.

REMEMBER: Lab notebook, Fritzing, breadboard, then code



Constants and Variables

It is often useful to give a name to something that will be used repeatedly in the code. Such items can be constants or variables:

- A **Constant** is a declaration that does not change throughout the code. For example, the pin that an LED is attached to.
- A **Variable** is a declaration that changes as the code processes. For example, a counter or index.

The use of Constants and Variables has several advantages:

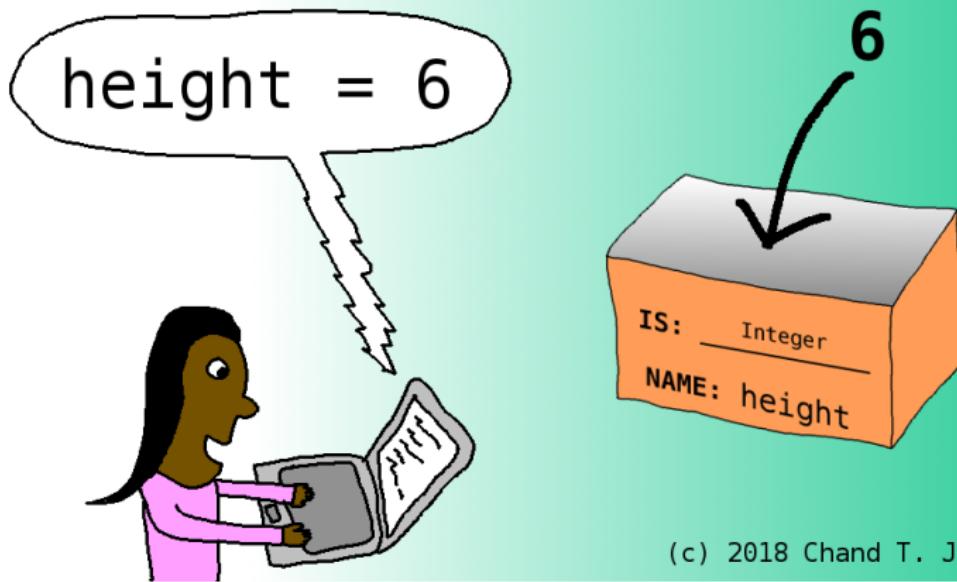
- It improves readability by assigning names to items.
- Items can be changed by editing a single declaration.
- It allows the code to do math.

The first two Data Types that we will be using:

- **int**: an Integer between $\pm 2,147,483,648$.
- **float**: a Floating point number with 7-digits precision.



Just a place to store data





IoT Style Guide - camelCase



Camel Case is the practice of writing phrases without spaces or punctuation, indicating the separation of words with a single capitalized letter, and the first word starting with either case. In IoT, we will start the first word as lowercase and subsequent words with upper case to delineate words.



Operators

There are a number of operators that act on variables:

```
1 // Assignment
2 x = y;      // assign x to be equal to y
3
4 // Math Operators
5 sum = x + y;
6 difference = x - y;
7 product = x * y;
8 quotient = x / y;
9 remainder = x % y;
10
11 // Incrementing
12 i = i + 1;
13 i += 1;
14 i++;
15
16 // Decrementing
17 i = i - 1;
18 i -= 1;
19 i--;
20
21 // Comparison
22 (x == y); // true if x is equal to y
23 (x != y); // true if x is not equal to y
24 (x > y); // true if x is greater than y
25 (x >= y); // true if x is greater than or equal to y
26 (x < y); // true if x is less than y
27 (x <= y); // true if x is less than or equal to y
```

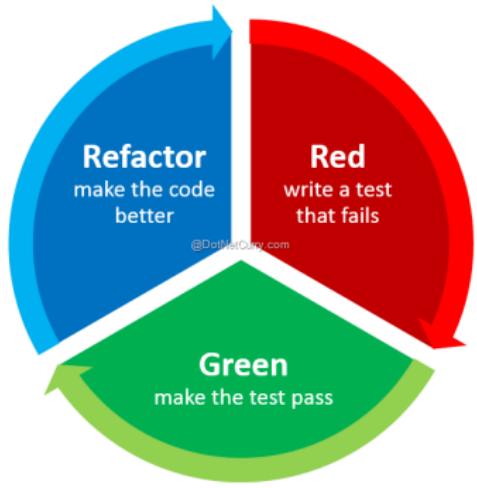


Constants and Variables Example

```
1 const int LEDPIN = D1;
2 const int LEDDELAY = 1000;
3 int i;
4
5 void setup() {
6     pinMode(LEDPIN, OUTPUT); //set LEDPIN as Output
7     i = 100;
8 }
9 void loop() {
10    digitalWrite(LEDPIN, HIGH);
11    delay(LEDDelay);
12    digitalWrite(LEDPIN, LOW);
13    delay(LEDDelay+i);
14    i = i + 100;
15 }
```



Assignment L02_02_helloLEDvar



- Refactor your L02_01_helloLED code to use constants and/or variables.

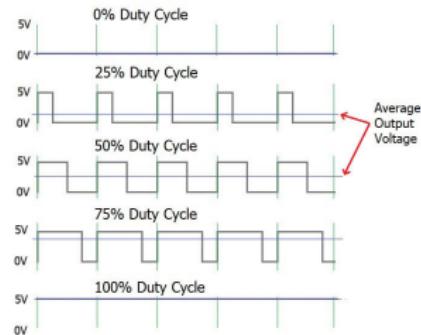
Note: refactoring code is when you rewrite portions of your code to make it more readable, or to make it run more efficiently.



Pulse Width Modulation

GPIO Pins are software configurable. They can be Output or Input. And, they can be Digital or Analog.

- Digital Output: High/Low (3.3V/0V)
- Analog Output: 0V to 3.3V PWM
- Digital Input: High/Low (3.3V/0V)
- Analog Input: 0V to 3.3V



All pins are capable of Digital (Input or Output). Consult the Particle Pinout for which Analog functionality is available on specific pins.



Assignment L02_03_helloLEDDigital



- ➊ We need to use a PWM pin, so continue to use the LED and current limiting resistor connected to pin D1.
- ➋ Use analogWrite to change the brightness of the LED (holding for 5 seconds between changes), using values:
 - 255
 - 63
 - 171
 - 16
- ➌ Measure the voltage with your multimeter at each value.

Syntax: `analogWrite(pin,value);`

- pin: the pin to write to
- value: the duty cycle of the pulses, an int between 0 (always off) and 255 (always on)

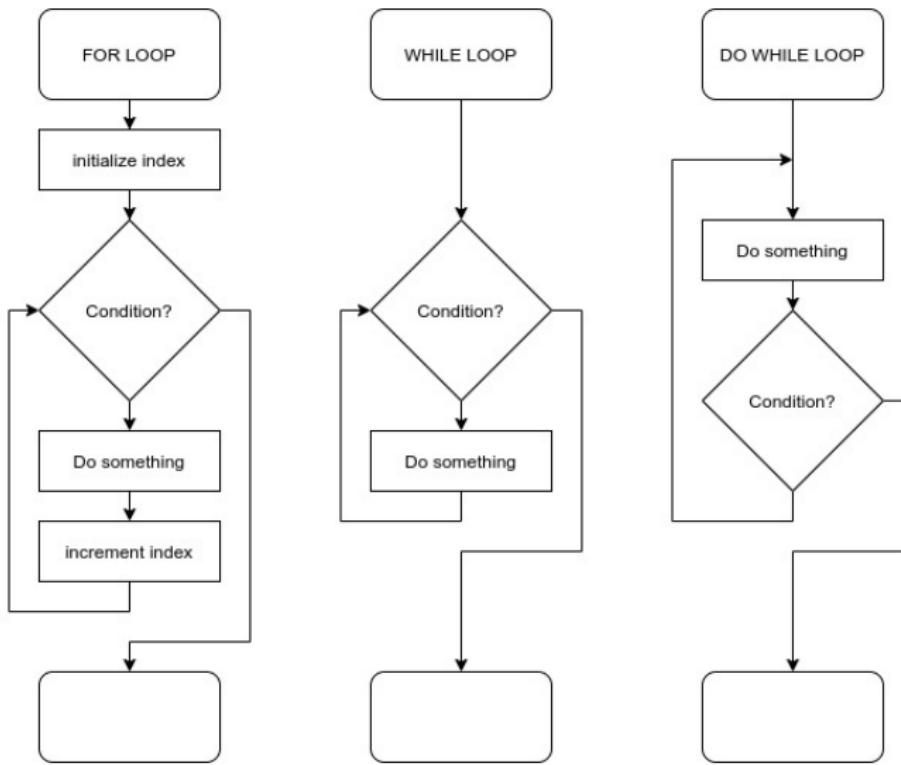


Flowcharts

Symbol	Name	Function
	Process	Indicates any type of internal operation inside the Processor or Memory
	input/output	Used for any Input / Output (I/O) operation. Indicates that the computer is to obtain data or output results
	Decision	Used to ask a question that can be answered in a binary format (Yes/No, True/False)
	Connector	Allows the flowchart to be drawn without intersecting lines or without a reverse flow.
	Predefined Process	Used to invoke a subroutine or an Interrupt program.
	Terminal	Indicates the starting or ending of the program, process, or interrupt program
	Flow Lines	Shows direction of flow.



Loops





FOR Loop syntax

```
1 // FOR loop syntax
2 for (initialization; condition; increment) {
3     // statement(s);
4 }
5
6 // EXAMPLE
7 for (j=0; j <= 255; j++) {
8     analogWrite(LEDPIN, j);
9 }
```

Note: the third parameter of a FOR loop can also decrement; i.e. $j--$ or can go up or down by a specified amount; i.e. $j = j + 2$



WHILE loop syntax

```
1 // WHILE loop syntax
2 while (condition) {
3     // statement(s)
4 }
5
6
7 // EXAMPLE
8 while (button == HIGH) {
9     digitalWrite(LEDPIN, HIGH);
10 } //continue this loop until button is released
```



For vs While Loops - Definate vs Indefinate

Loop A Defined Number of Times

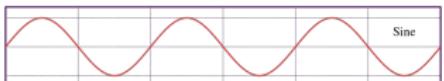


Loop A Undetermined Number of Times





Assignment L02_04_helloLEDtri



- Using FOR Loops, have the LEDs follow a Triangle Wave function from off to full brightness and back to off with a period of 10 seconds.
- EXTRA CREDIT: add a second LED, have it follow an inverted triangle (full on to off) simultaneously as the first LED goes from off to full brightness.

Before you write code, create a flow chart of the logic to create a triangle wave.



While or Do While





Number Systems

Decimal

92₁₀

Digits: 0,1,2,3,4,5,6,7,8,9

Binary

01011100₂

Digits: 0,1

Hexadecimal

5C₁₆

Digits: 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F

Octal

134₈

Digits: 0,1,2,3,4,5,6,7



Exponents

Whole Number Exponents

whole # exponent \rightarrow

$$x^a = \underbrace{x \cdot x \cdot x \cdot \dots \cdot x}_{a \text{ times}}$$

base

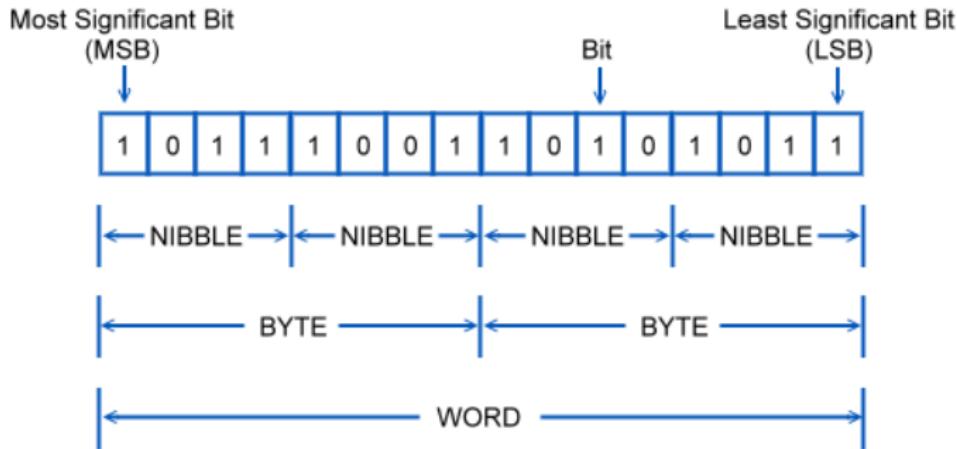
Example: $2^3 = 2 \cdot 2 \cdot 2 = 8$

The rule for zero as an exponent:

Any nonzero real number raised to the power of zero is one, this means anything that looks like x^0 will always equal 1 if x is not equal to zero.



Bits, Nibbles, Bytes, and Words





Data Types: Numbers

Data Type	8-bit AVR systems (Arduino Uno)				32-bit ARM systems (Teensy 3.2)		
	bytes	range (signed)	range (unsigned)	bytes	range (signed)	range (unsigned)	
char	1	-128 to 127	0 to 255	1	-128 to 127	0 to 255	
short	2	+/- 32,767	0 to 65,353	2	+/- 32,767	0 to 65,353	
int	2	+/- 32,767	0 to 65,353	4	+/- 2,147,483,648	0 - 4,294,967,295	
long	4	+/- 2,147,483,648	0 - 4,294,967,295	4	+/- 2,147,483,648	0 - 4,294,967,295	
long long	8	+/- 9,223,372,036,854,770,000	0 to 18,446,744,073,709,551,615	8	+/- 9,223,372,036,854,770,000	0 to 18,446,744,073,709,551,615	
float	4	3.4E +/- 38 (7 digits)	n/a	4	3.4E +/- 38 (7 digits)	n/a	
double	4	3.4E +/- 38 (7 digits)	n/a	8	1.7E +/- 308 (15 digits)	n/a	
long double	8	1.7E +/- 308 (15 digits)	n/a	8	1.7E +/- 308 (15 digits)	n/a	
Unambiguous							
uint8_t	1	n/a	0 to 255	1	n/a	0 to 255	
int8_t	1	-128 to 127	n/a	1	-128 to 127	n/a	
uint16_t	2	n/a	0 to 65,353	2	n/a	0 to 65,353	
int16_t	2	+/- 32,767	n/a	2	+/- 32,767	n/a	
uint32_t	4	n/a	0 - 4,294,967,295	4	n/a	0 - 4,294,967,295	
int32_t	4	+/- 2,147,483,648	n/a	4	+/- 2,147,483,648	n/a	

There are 7.5×10^{18} grains of sand on Earth. A long long integer and the floating point numbers are larger than this.

MATH NOTE: An Integer divided by an Integer always returns an Integer



Math Warning and Type Casting

Be cognizant of the data type when performing math operations.

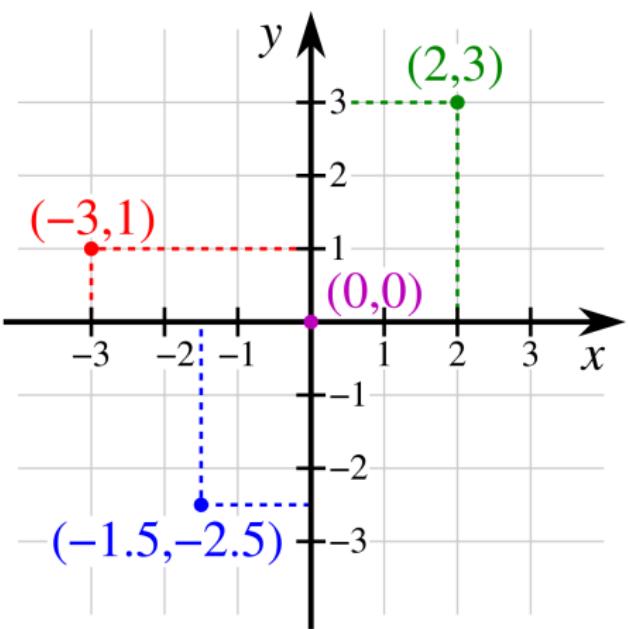
```
1 int x = 3;
2 int y = 2;
3 float yf = 2.0;
4 float z;
5
6 //int divided by an int returns an int
7 z = x/y;                      // z = 1.0
8 z = x/yf;                     // z = 1.5
9 z = x / 2;                    // z = 1.0
10 z = x / 2.0;                 // z = 1.5
11
12 //type casting used to change datatype
13 z = (float) x / (float) y;   // z = 1.5
14 z = x / (float) y;          // z = 1.5
15
16 z = (int) (x / yf);        // z = 1.0
17 y = x / yf;                // y = 1
```

Type Casting is a way to ensure that you are correctly moving between datatypes



A Dive in Math: Cartesian Coordinates

The Cartesian coordinate system is based on a rectangular grid that relies on a grid of vertical and horizontal lines to locate a position.



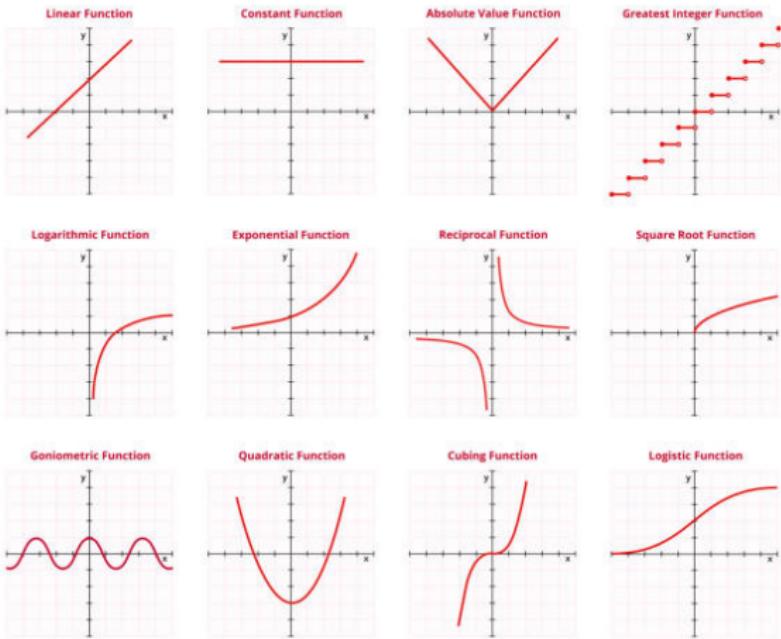


A Dive in Math: Algebraic Functions

An algebraic function provides a "y-value" for every "x-value"

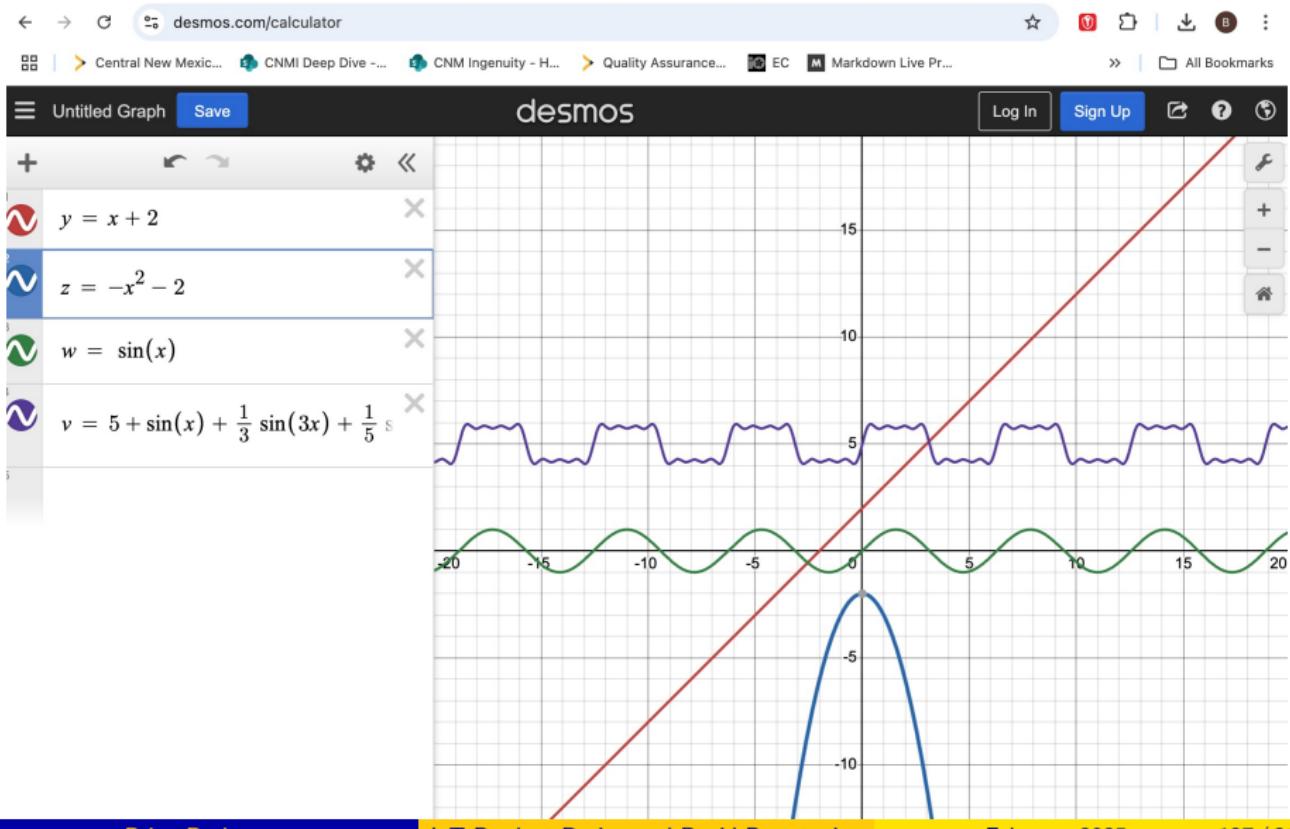
- Linear: $y = x + 2$
- Quadratic: $y = x^2$
- Periodic: $y = \sin(x)$

12 BASIC FUNCTIONS



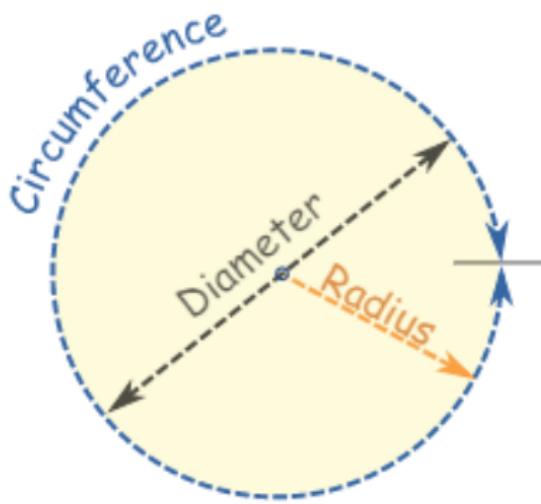


A Dive in Math: Desmos Fun





Pi (π)

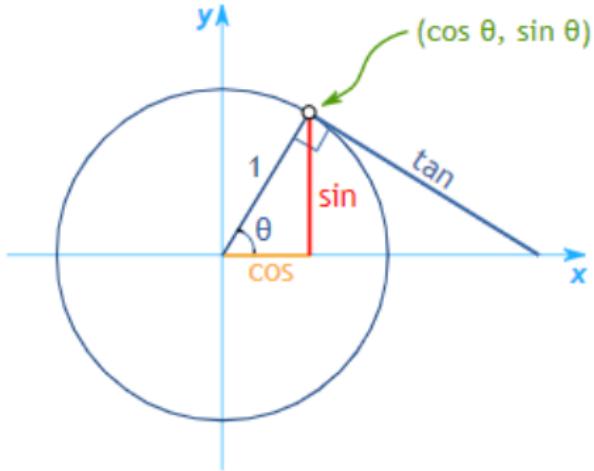
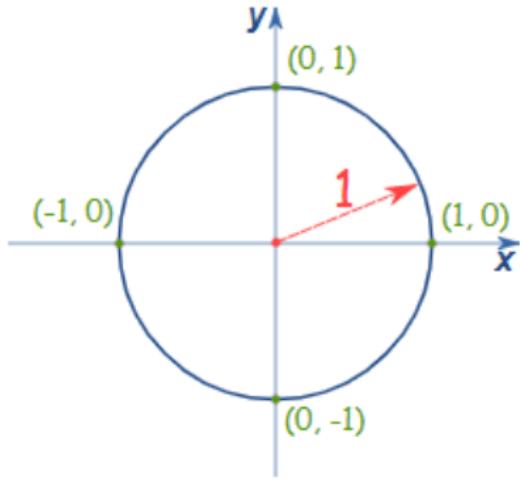


$$\frac{\text{Circumference}}{\text{Diameter}} = \pi = 3.14159\dots$$



Unit Circle and Trigonometric Functions

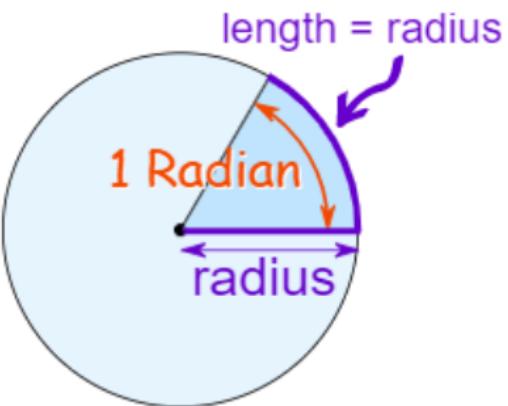
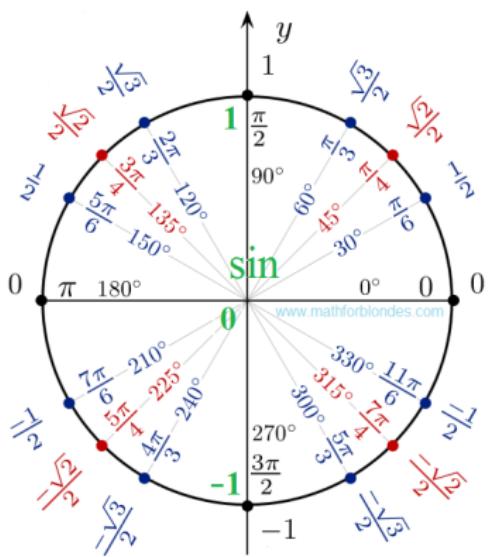
The Unit Circle is a circle with a radius of 1.



The Unit Circle can be used to map out the trigonometric values of sine, cosine, and tangent.



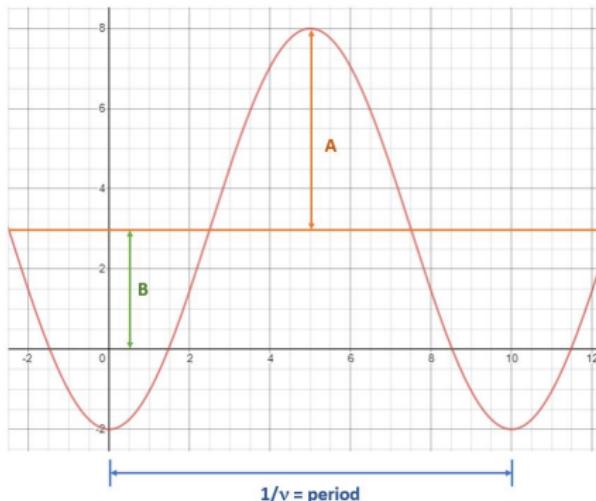
Unit Circle and the Value of $\sin(\theta)$



- $\sin(\theta)$ is the y-value of the point on the Unit Circle at angle θ .
- In our trig functions, θ is measured in radians (rad), not degrees.
- 360 degrees = 2π radians.



Sine Waves

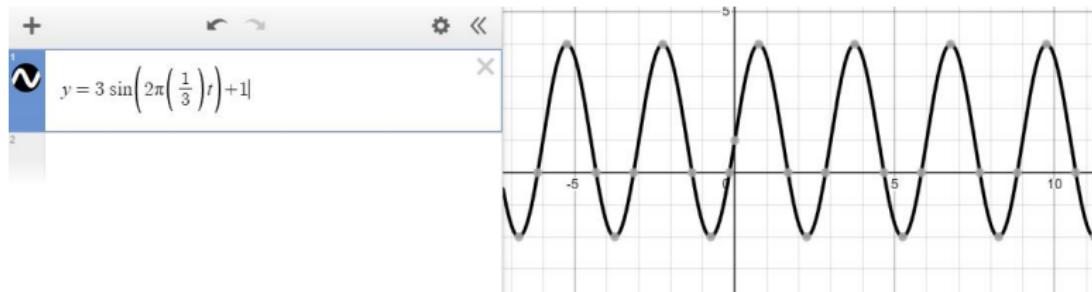
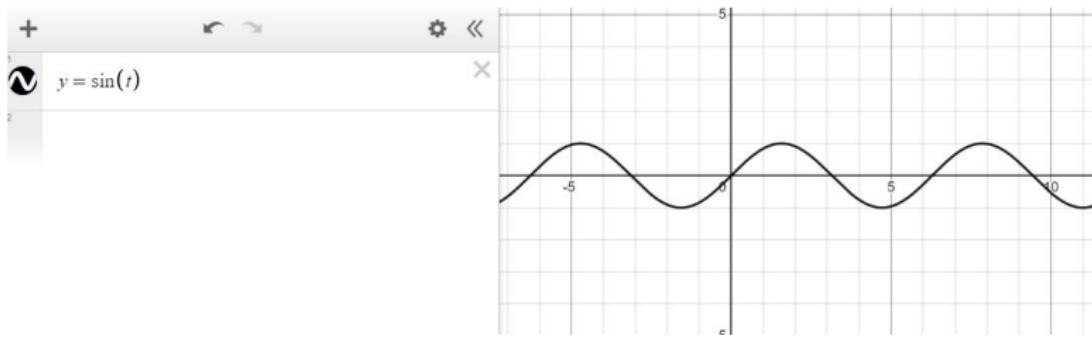


$$y = A * \sin(2 * \pi * \nu * t) + B$$

where A = amplitude, B = offset, ν = frequency = $\frac{1}{\text{period}}$,
and t = time in seconds.



Using Desmos (desmos.com/calculator)





Header Files

A header file is a file with the extension .h which contains C function declarations and macro definitions to be shared between several source files. There are two types of header files; those that the programmer writes and those that come with the compiler.

Both the user and system header files are included using the preprocessing directive #include. It has the following two forms:

- `#include <file.h>` for system header files.
- `#include "file.h"` for user-created header files in the directory that contains the current code.

An example of a system header file is the math.h header that defines various mathematical functions.

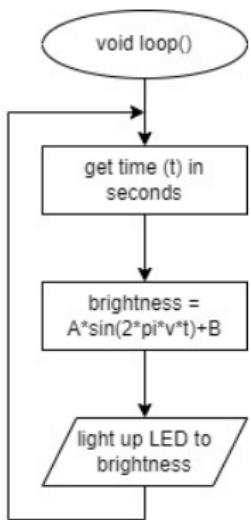


Basic Structure of IoT Program Revisited

```
1 #include <math.h>          // include header files
2 const int LEDPIN = 5;      // declare constants
3 float value,n;            // declare variables
4
5 void setup() {             // runs once
6     pinMode(LEDPIN,OUTPUT); // system settings
7     n = 0;                 // set variables
8 }
9
10 void loop() {              // loops indefinitely
11     value = sin(2*M_PI*n);
12     n = n+0.25;           // move a quarter around
13                             // the unit circle
14 }
```



Assignment L02_05_helloLEDsin



Use a `sin()` function to vary the brightness of your LED.

- Use `math.h`.
- Function `sin()` takes a float as an input and returns a float.
- `M_PI` is used for the value of π
- Set the period to 5 seconds.

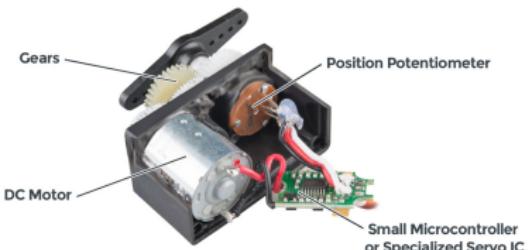
Recall: for a sin wave: $y = A * \sin(2 * \pi * \nu * t) + B$

The function `millis()` returns milliseconds since the Particle has been powered on. For the sine equation, use $t = \text{millis()} / 1000.0$.



Servo Motors

- A servo is any motor-driven system with a feedback element built in.
- A servo motor basically has three core components:
 - ① a DC motor,
 - ② a potentiometer that measures its position,
 - ③ a feedback controller circuit
- The servo is controlled by a PWM signal from a digital pin. The width of the pulse determines the position that the servo moves to.





Servo commands

- ① Header - declare the Servo and give it a name (i.e., myServo)
 - Servo myServo; - create object myServo of class Servo
- ② void setup() - similar to pinMode() connect it to a pin
 - myServo.attach(pin) - attach the Servo to a pin (this must be a PWM pin)
- ③ void loop() - similar to analogWrite()
 - myServo.write(angle) - move servo to angle (in degrees)



Assignment: L02_06_Servo



① L06_01_Servo

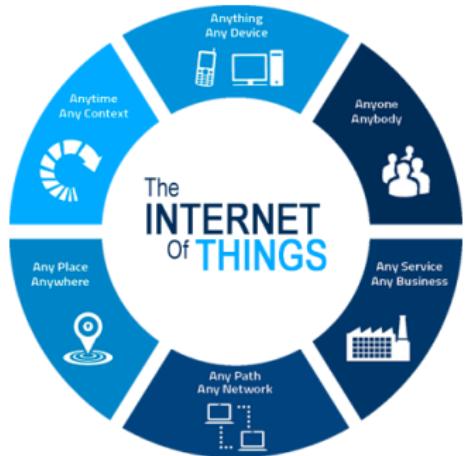
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- Connect the servo and a button to the Particle
- Create a HelloServo-type code that moves the servo to 180 degrees, waits, and then moves it to zero.
- Modify the code to have the servo oscillate between 0 and 180 degrees using a sine wave pattern.
- Have the button to start and stop the motion.
- Extra: Have the motion begin again at the point in the cycle where it stops.

Recall, in C++ (`math.h`) the math constants are `M_<name>`. For example, `M_PI` = π .



Module 2 Review



- Learning Objectives

- 1 Basic Electrical Circuits - Resistors and Diodes
- 2 Using a Multimeter
- 3 Constants and Variables
- 4 Digital and Analog Outputs
- 5 For and While Loops
- 6 Counting in Binary

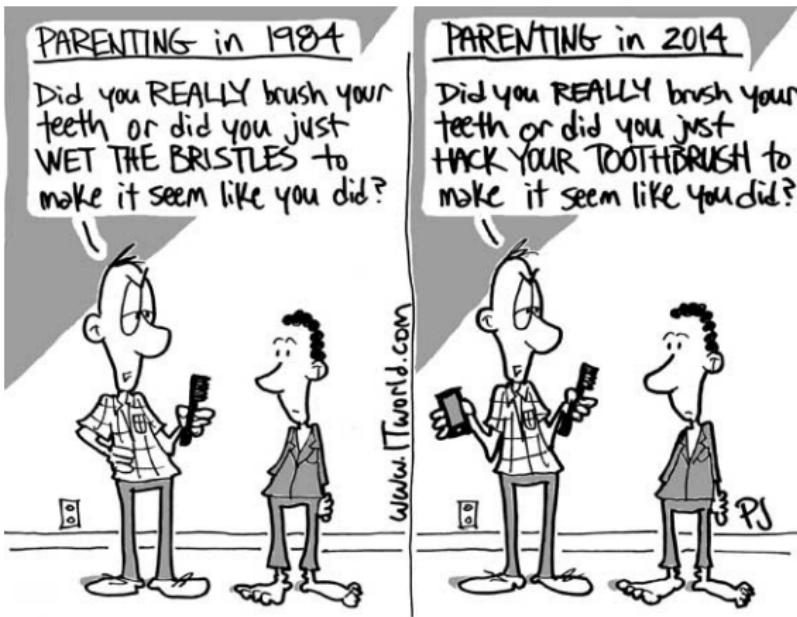
- Additional Items

- 1 Wood or Metal shop
- 2 Fritzing
- 3 Quiz 1

Module 3 - Buttons

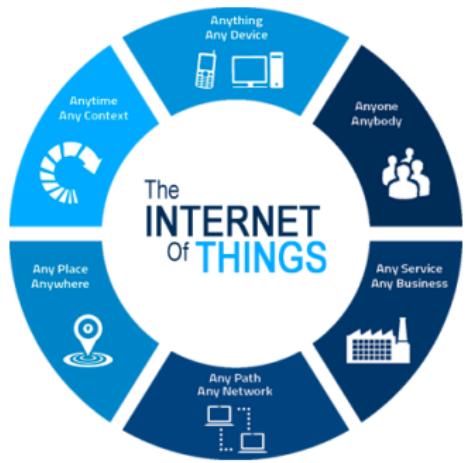


IoT Fun





Module 3 Objectives



- Learning Objectives

- 1 Serial Monitor
- 2 Buttons
- 3 Digital / Analog Inputs
- 4 Condition Statements
- 5 Particle Cloud Publishing

- Additional Items

- 1 3D Modeling Lesson 1 - Personalized Lego
- 2 Quiz 2



Displaying to the Screen: The Serial Monitor

```
1 #include "particle.h"
2
3 int count = 37;
4
5 SYSTEM_MODE(SEMI_AUTOMATIC)
6
7
8 void setup() {
9 // Enable Serial Monitor
10 Serial.begin (9600);
11 waitFor(Serial.isConnected,10000); // wait for Serial monitor
12 Serial.printf("Ready to Go\n");
13 }
14
15 void loop() {
16 Serial.printf("I have %i skittles, do you want any?",count);
17 }
```

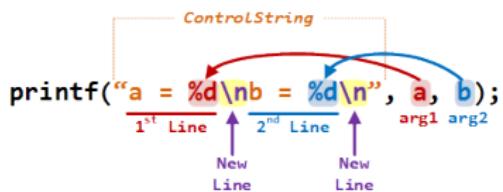


Print Statements

- ① Serial.print() prints data to the monitor through the serial port as human-readable text:
 - Serial.print('N') prints: N (works for single character only)
 - Serial.print("Hello World") prints: Hello World
 - Serial.print(78) prints: 78
 - Serial.print(3.141592) prints 3.14
 - Serial.print(3.141592,5) prints 3.14159
- ② Serial.println() displays the print() followed by a carriage return (\r) or newline (\n).
- ③ Serial.printf() displays a formatted print.



Format Specifiers Statements



specifier	Output	Example
d or i	Signed decimal integer	392
u	Unsigned decimal integer	7235
o	Unsigned octal	610
x	Unsigned hexadecimal integer	7fa
X	Unsigned hexadecimal integer (uppercase)	7FA
f	Decimal floating point, lowercase	392.65
F	Decimal floating point, uppercase	392.65
e	Scientific notation (mantissa/exponent), lowercase	3.9265e+2
E	Scientific notation (mantissa/exponent), uppercase	3.9265E+2
g	Use the shortest representation: %e or %f	392.65
G	Use the shortest representation: %E or %F	392.65
a	Hexadecimal floating point, lowercase	-0xc.90feP-2
A	Hexadecimal floating point, uppercase	-0XC.90FEPE-2
c	Character	a
s	String of characters	sample
p	Pointer address	b8000000
n	Nothing printed. The corresponding argument must be a pointer to a signed int. The number of characters written so far is stored in the pointed location.	
%	A % followed by another % character will write a single % to the stream.	%

```
1 int count = 42;
2 float value = 3.14159;
3 Serial.printf("Print an integer %i and a float %0.4f\n",count,value);
4
5 //Output: Print an integer 42 and a float 3.1416 (it rounded the last digit)
```



Opening the Serial Monitor

Access the Command Palette - Ctrl-Shift-P

The screenshot shows the Particle IDE's Command Palette open. The search bar at the top contains the text '>particle'. Below the bar, a list of recent commands is displayed, each preceded by a blue 'Particle' icon. The commands are:

- Particle: Install Library
- Particle: Find Libraries
- Particle: Cloud Compile
- Particle: Configure Workspace for Device
- Particle: Launch CLI
- Particle: Install Local Compiler
- Particle: Cloud Flash
- Particle: Serial Monitor
- Particle: Create New Project
- Particle: Audit Environment
- Particle: Who Am I?
- Particle: Clean application (local)
- Particle: Clean application & DeviceOS (local)

Two sections are labeled on the right side of the list:

- 'recently used' above the first five items.
- 'other commands' above the last two items.

Or, open the Serial Monitor in Git Bash, Powershell or Terminal:

```
1 particle serial monitor --follow
```



Assignment L03_00_SerialMonitor



- In void setup() using serial.printf():
 - ➊ Print Hello World!
 - ➋ On a new line, then using a for() loop and the specified %i, print the numbers 1 through 12, each followed by a comma
 - ➌ Finally, print the number 13 followed by a newline and then the words All Done
- void loop() should be blank, but still needs the { }

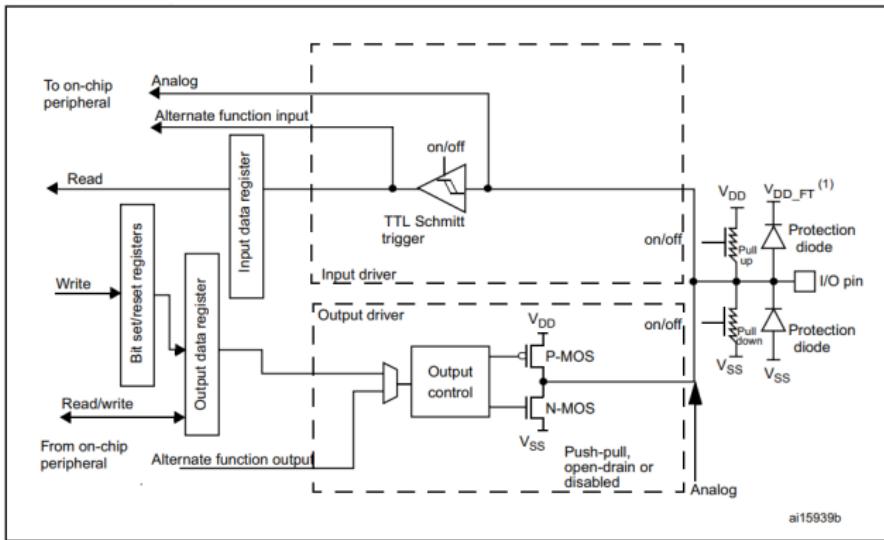
1 Hello World!

2 1,2,3,4,5,6,7,8,9,10,11,12,13

3 All Done



One Pin - Many Functions



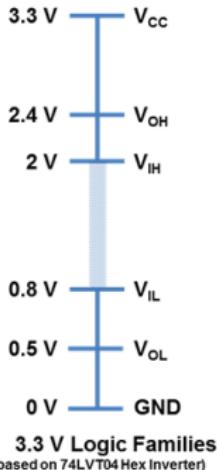
ai15939b

Software Programmable: Input or Output and Digital or Analog.



Digital Input/Output

Digital electronics rely on binary logic to store, process, and transmit data or information. Binary Logic refers to one of two states – ON or OFF. This is commonly translated as a binary 1 or binary 0. A binary 1 is also referred to as a HIGH signal and a binary 0 is referred to as a LOW signal.

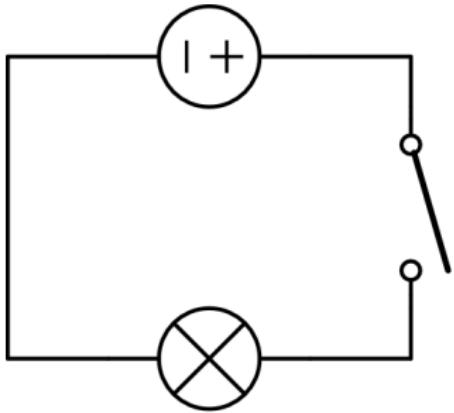


- `digitalWrite(pin,value);`
- `inputValue = digitalRead(pin);`

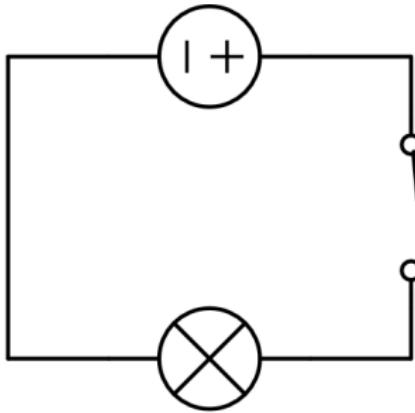
where, value equals HIGH or LOW.



Switches



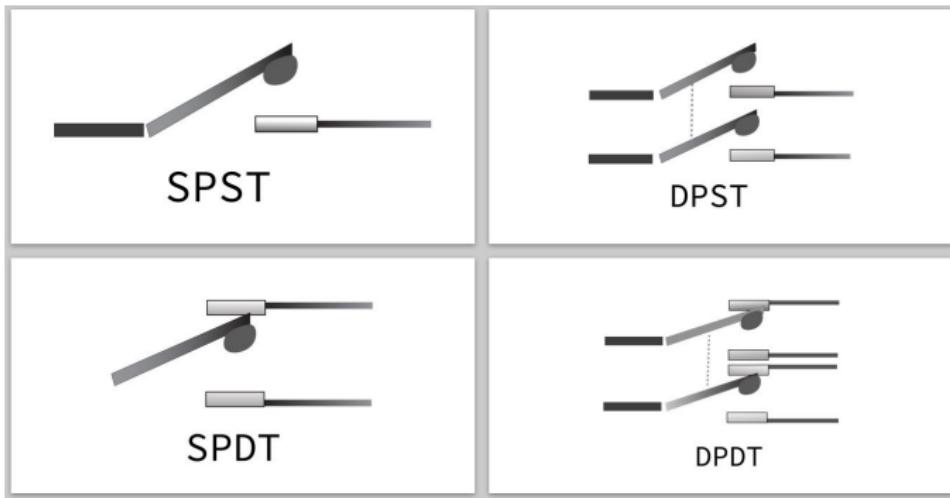
Lamp Off



Lamp On



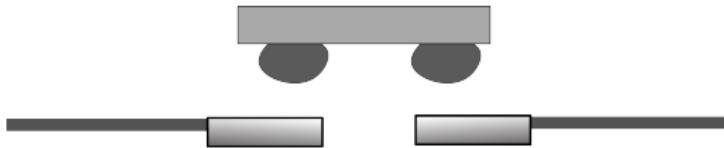
Poles and Throws



- Poles indicates the number of circuits that one switch can control for one operation of the switch.
- Throws indicates the number of contact points.



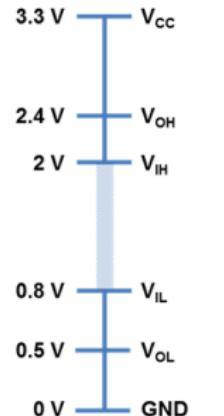
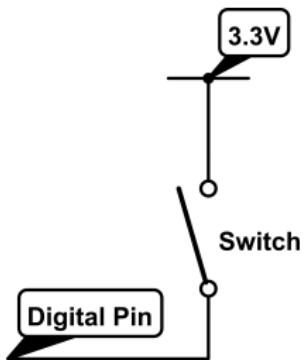
A Button - SPST



SPST
double break



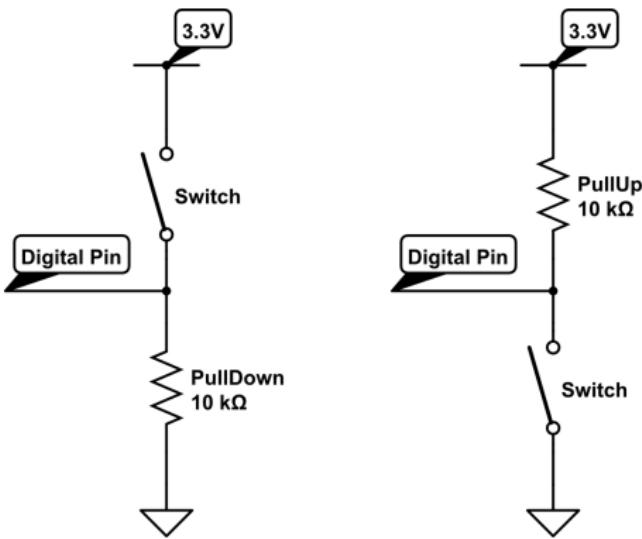
Floating Inputs



3.3 V Logic Families
(based on 74LVT04 Hex Inverter)



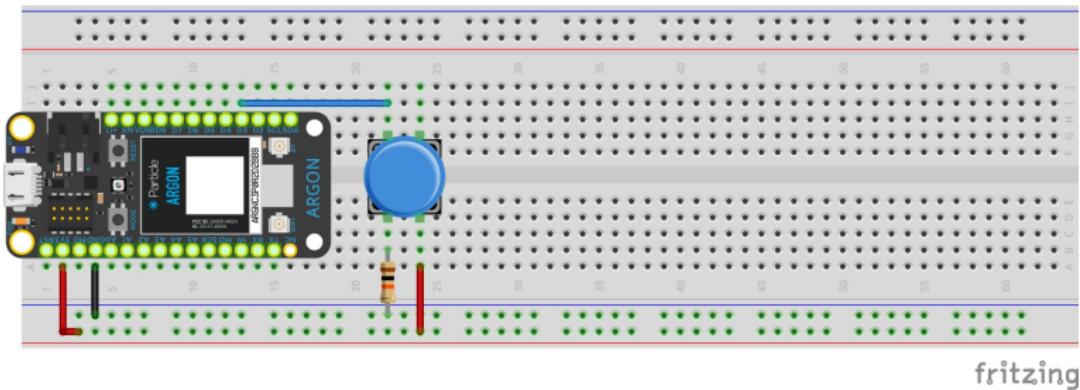
Pull Down and Pull Up Resistors



- What happens if the digital pin is left floating when the switch is open?
- What happens if the pin is connected directly to GND (or V_{cc}) without a resistor?



Our First Button and Pull Down Resistors

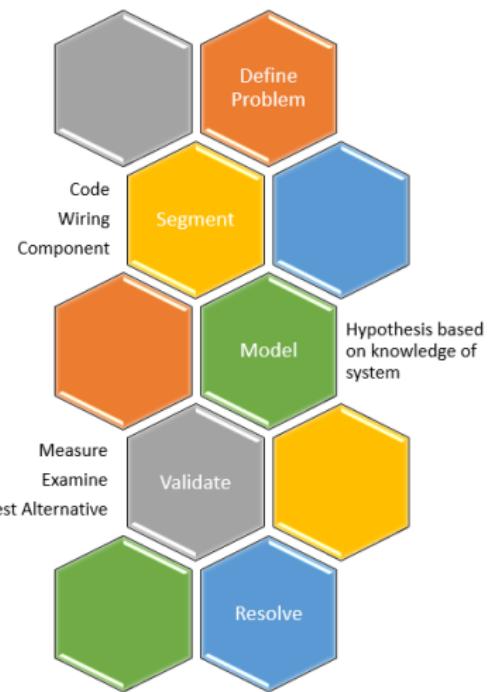


Reading from a digital pin:

- `inputValue = digitalRead(pin);`
where
 - pin is the digital pin that the button is connected to
 - inputValue is an int (declared in the header)



Model Based Troubleshooting





Fishbone Diagram

Code Setup

Wrong Pin Type
Forgot PinMode
Not Initialized
Forgot .Begin()

Wiring

No GND
Wrong Bus
No Power
Wrong Pin

Problem

Wrong Variable Name
%i vs %f
Digital vs Analog
Delay
Data not retained

Code Usage

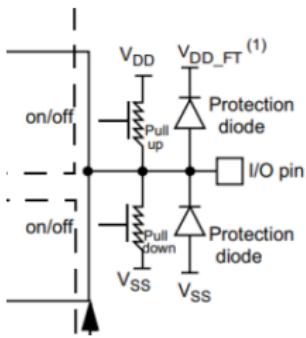
Device

Broken
Wrong Device

Draw a blank fishbone in your notebook (across 2 pages)



Assignment: Buttons



Connect a button (and a multimeter to measure the voltage) to Pin D3.

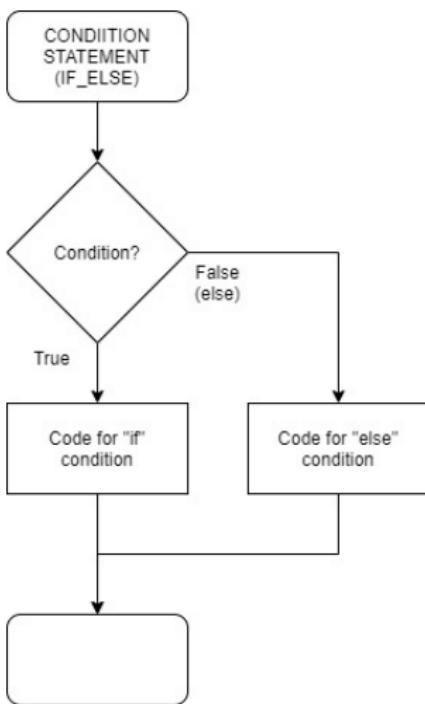
① L03_01_button

- Use `digitalRead()` to input the button state.
- Print button state to the screen.
- Remove the resistor. How does this affect the button state and the voltage?
- Replace the pull-down resistor with a pull-up. How does the logic change?
 - Not pressed: 3.3V
 - Pressed: GND
- Return to the "pull-down" configuration but without the pull-down resistor.
 - Implement:
`pinMode(pin,INPUT_PULLDOWN);`

- Notebook: draw circuit
- Fritzing diagram
- Wire your circuit
- Write the code



IF-ELSE Statements



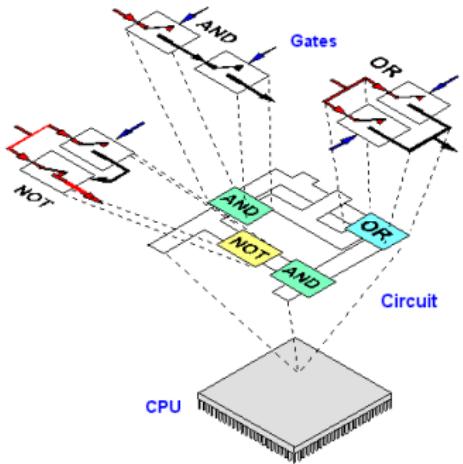


IF-ELSE Statements

```
1 // IF statement SYNTAX
2 if (condition) {
3     //statement(s)
4 }
5 else {
6     // else statement(s)
7 }
8
9 // EXAMPLE
10 if (buttonState == 1) {
11     Serial.printf("Button is pressed \n");
12 }
13 else {
14     Serial.printf("Button is not pressed \n");
15 }
```



Data Types: Boolean and Boolean Logic



Boolean datatype (bool)
holds either a TRUE or
FALSE

Boolean Logic Operations

- ① NOT (!): true if operand is false and visa-versa
 - $x = !x$
- ② AND (&&): true if both operands are true
 - $z = x \&\& y$
- ③ OR (||): true if either operand is true
 - $z = x \parallel y$

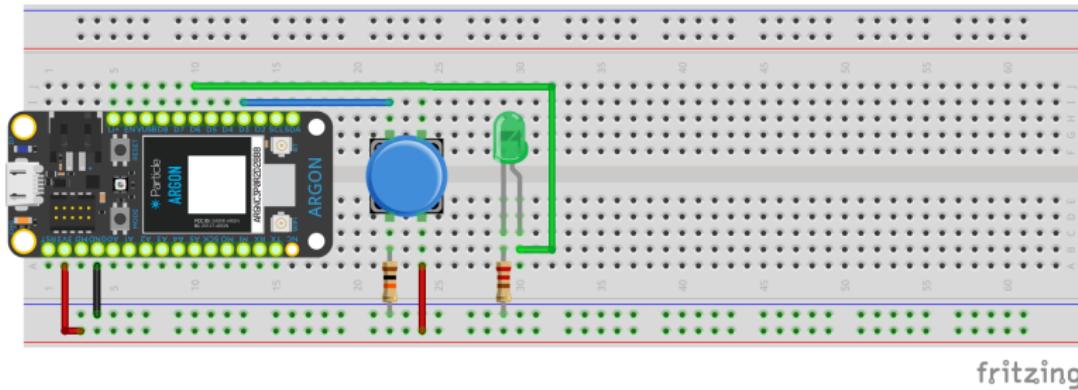


Boolean Logic In Action

```
1 bool x;
2 bool buttonState1, buttonState2;
3 int y, z;
4
5 // ! (NOT) assignment function
6 x = !x;           // toggle x (if x = true (1), then set x = false (0), and visa-versa)
7
8 // ! (NOT) comparison
9 if (!x) {         // if x is false. This is the same as: if(x != true)
10   // do something
11 }
12
13 // LOGICAL AND: if both pins are pressed
14 buttonState1 = digitalRead(PIN1);
15 buttonState2 = digitalRead(PIN2);
16 if ((buttonState1) && (buttonState2)) { //if buttonState1 is true AND buttonState2 is
17   true
18   // do something
19 }
20
21 // LOGICAL OR: if either value is greater than zero
22 if (y > 0 || z > 0) {
23   // do something
24 }
```



Button and LED





Assignment: Buttons and LEDs



Update your
schematic and
Fritzing

① L03_02_buttonLED

- Add a Green LED to Pin D6 and use D3 button to turn the LED on/off.
- Also, print button state to the screen

② L03_03_twoButtonLED

- Add a second button (Pin D2) and Yellow LED (Pin D5).
- Have each button control one LED.
- Also, print button states to the screen.

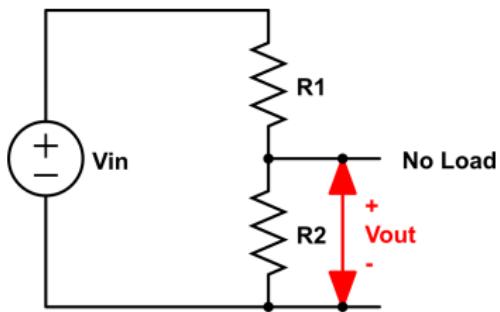
③ Extra Credit: Modify twoButton

- The Green LED lights up if both buttons are pressed
- The Yellow LED lights up if either button is pressed

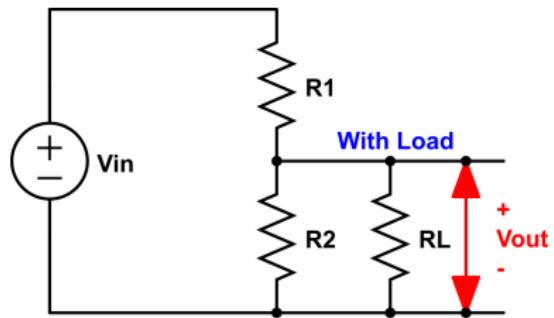


Resistors in Series and Parallel

Open Circuit Behavior



Behavior Under Load

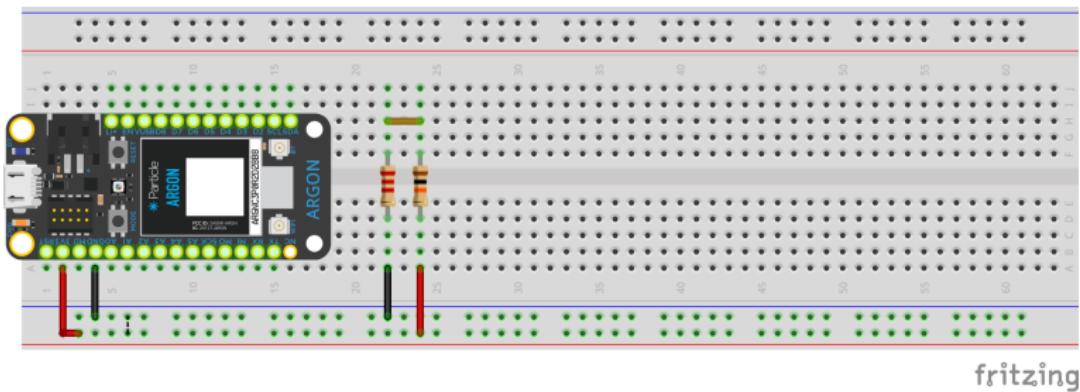


$$V_{out} = V_{in} \frac{IR_2}{I(R_1+R_2)} = \frac{R_2}{R_1+R_2} V_{in}$$

$$V_{out} = \frac{R_2 \parallel R_L}{R_1 + R_2 \parallel R_L} V_{in}$$



Voltage Dividing

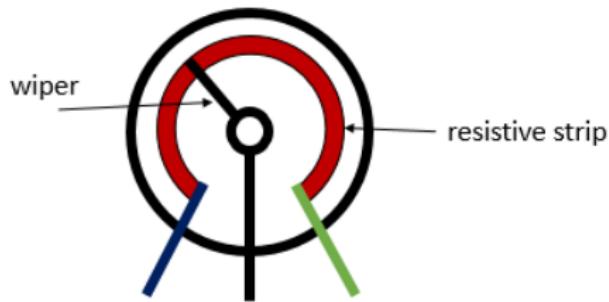


We are just using the Particle to provide Power and GND.

- Use various combinations of resistors between $1k\Omega$ and $22k\Omega$.
- Calculate the Series resistance and the voltage between the two resistors in your Lab Notebook.
- Measure with your multimeter and compare.



Potentiometer - Variable Resistor

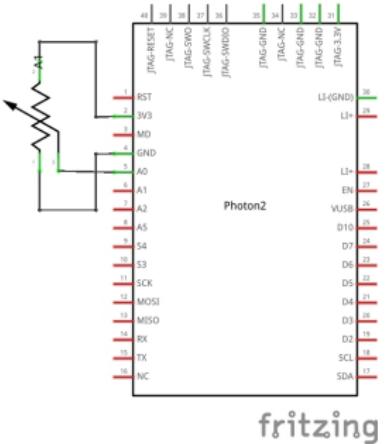


A potentiometer has 3 pins. Two terminals (the blue and green) are connected to a resistive element and the third terminal (the black one) is connected to an adjustable wiper.



Assignment L03_04_AnalogInput

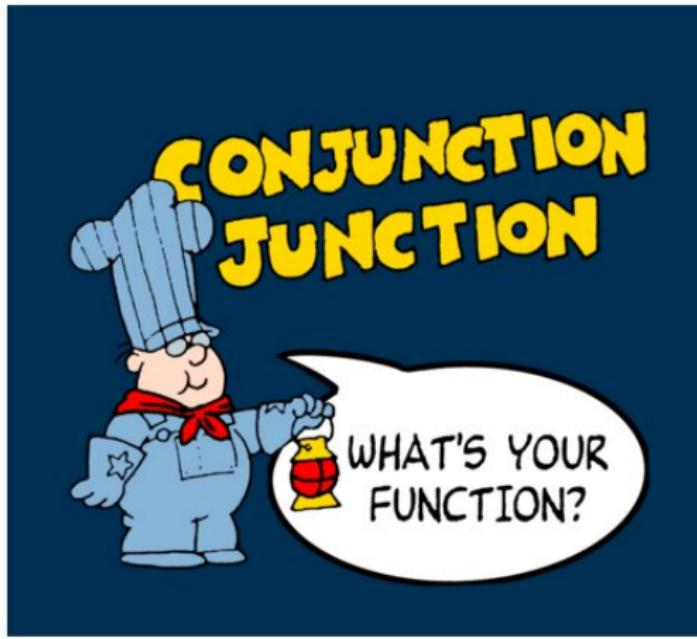
Similar to L03_01_Button, read an analog input and print the value to the serial monitor using `Serial.printf()`:



- 1 Look up the syntax of `analogRead()` on the Particle "Docs" website:
docs.particle.io/reference/device-os/api/input-output/analogread-adc
- 2 Utilize `analogRead()` to measure analog input across a potentiometer (voltage divider) using Pin A0.
- 3 Determine the range of the `analogRead()` across the entire range of the potentiometer.



Conjunction Junction





Anatomy of a Function

Anatomy of a C function

Datatype of data returned, any C datatype

"void" if nothing is returned

```
int myMultiplyFunction(int x, int y){  
    int result;  
    result = x * y;  
    return result;  
}
```

Function name

Parameters pass to function, any C datatype

Return statement, datatype matches declaration

Curly braces required



Functions in Action

```
1 int variable1, variable2, answer;
2
3 // Declare (or prototype) the function in the header
4 int myMultiplyFunction(int x, int y);
5
6 void setup() {
7     Serial.begin(9600);
8     variable1 = 3;
9     variable2 = 5;
10 }
11
12 void loop() {
13     // Call the function
14     answer = myMultiplyFunction(variable1, variable2);
15     Serial.printf("%i times %i = %i\n", variable1, variable2, answer);
16     variable2 = answer;
17 }
18
19 // Define the function
20 int myMultiplyFunction(int x, int y) {
21     int result;
22
23     result = x * y;
24     return result;
25 }
```

The function needs to be: Declared, Defined, and Called (at least once)



Types of Variables

```
1 int x;           // x is a global variable available in the entire program
2 int addx();      // declaration of function
3 void setup() {
4     x = 1;
5 }
6 void loop() {
7     x = addx();
8 }
9 int addx() {
10     int y = 0;      // y is a local variable, resets every function call
11     static int z = 0; // z is a static local variable, maintains its value
12     y = y + x;      // x is global, so value exists in function
13     z = z + x;
14     Serial.printf("x = %i, y = %i, and z = %i \n",x,y,z);
15     return z;
16 }
```

① Global Variables

- Accessible throughout the program and all functions.

② Local Variables

- Accessible only in the function.
- Created when function is called. Destroyed when function is returned.

③ Static Local Variables

- Accessible only in the function.
- Maintains value across multiple calls of a function.

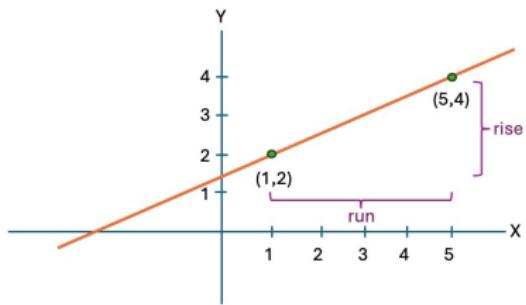


Basic Structure of IoT Program with Functions

```
1  /*
2   * This is an example of how to use functions
3   * The code below converts inches to feet
4   */
5 #include "particle.h"
6 const int INCHPIN=14;
7 int inches;
8 float feet;
9
10 float inchestoFeet(int measurement);
11
12 void setup() {
13     Serial.begin(9600); // Turn on Serial Monitor
14     waitFor(Serial.isConnected,10000);
15     pinMode(INCHPIN,INPUT);
16 }
17
18 void loop() {
19     inches = analogRead(INCHPIN);
20     feet = inchestoFeet(inches);
21     Serial.printf("%i inches equal %0.2f feet \n",inches, feet);
22     delay(1000);
23 }
24
25 float inchestoFeet(int measurement) {
26     float answer;          // declare answer as a local variable
27
28     answer = measurement / 12.0;
29     return answer;
30 }
```



Linear Conversion - Slope and Y-Intercept



$$y = mx + b$$

where m is slope and b y-intercept.

For example, given two points:

- $(x_1, y_1) = (1, 2)$
- $(x_2, y_2) = (5, 4)$

Find slope

- $m = \frac{\text{rise}}{\text{run}} = \frac{4-2}{5-1} = \frac{1}{2}$

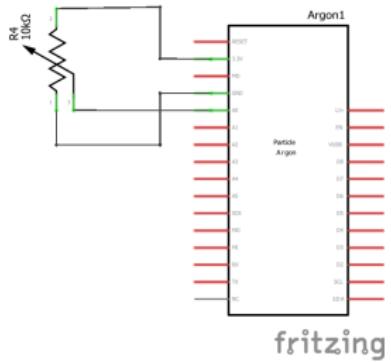
Find y-intercept

- $y_1 = m * x_1 + b$
- $b = y_1 - (m * x_1)$
- $b = 2 - (\frac{1}{2} * 1) = 1\frac{1}{2}$

Use this to find the conversion from Celsius to Fahrenheit.



Assignment L03_04_AnalogInput Revisited

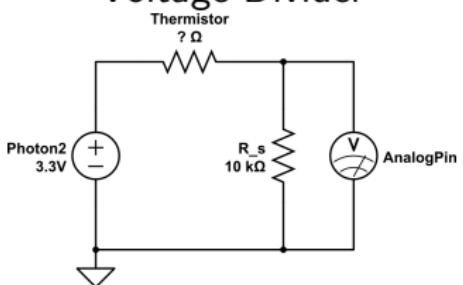


- ① Using the multimeter to measure voltage for 2 analogRead() values, find the linear conversion equation to convert from input value to voltage.
- ② Modify your code by adding a function, intoVolts(), that converts the analog input value to voltage.
- ③ Print both the raw analogInput and the associated voltage to your screen.

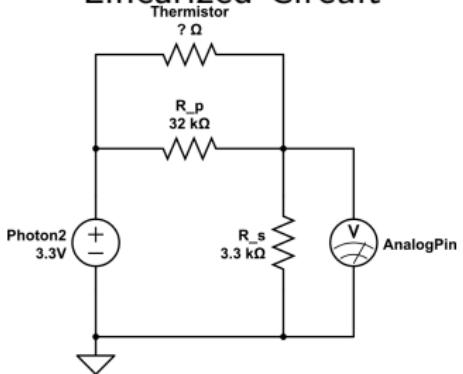


Assignment L03_05_Thermistor

Voltage Divider



Linearized Circuit



The thermistor is an element that changes its resistance in response to temperature changes.

- ① Using your Particle to provide power, but without code: Create a voltage divider with a $10\text{k}\Omega$. Measure the resistance if the Thermistor and voltage across the R_S resistor in
 - Room Temperature Water
 - Ice Water
 - Boiling Water
- ② Repeat with Linearized Circuit
- ③ Write code to print out temperature using an `analogRead()` and writing a function that converts voltage to temperature.

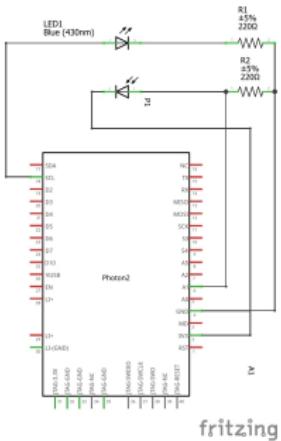


Photodiode

PARAMETERS	DIODE	PHOTODIODE
Definition	A diode is two terminal device which conducts when it is forwards biased.	A photodiode is a two terminal device which conducts when it is reversed biased.
Circuit symbol		
Main Function	Diode is mainly used as a switch.	Photodiode is used for conversion of light energy into electrical energy.
Material Used	Germanium or silicon, any of these two can be used.	Silicon is used for manufacturing photodiode. An anti-reflective layer of Silver Nitride is used for coating.
Applications	Used in clippers, clampers, rectifiers etc.	Used in optoelectronic device, camera, optocouplers etc.



Assignment: L03_06_HelloNightLight



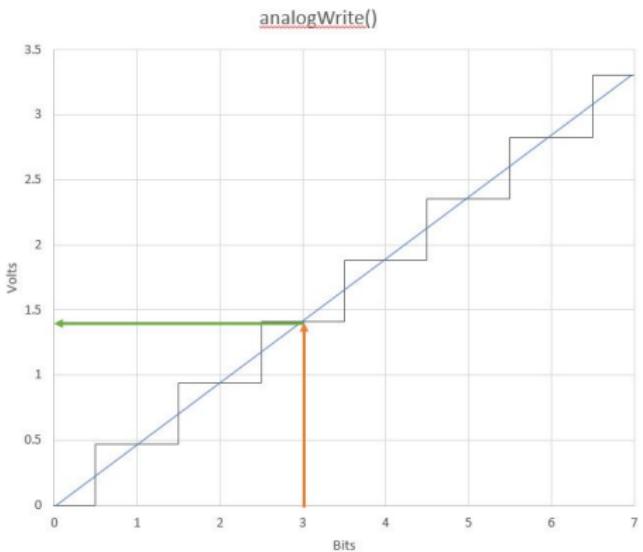
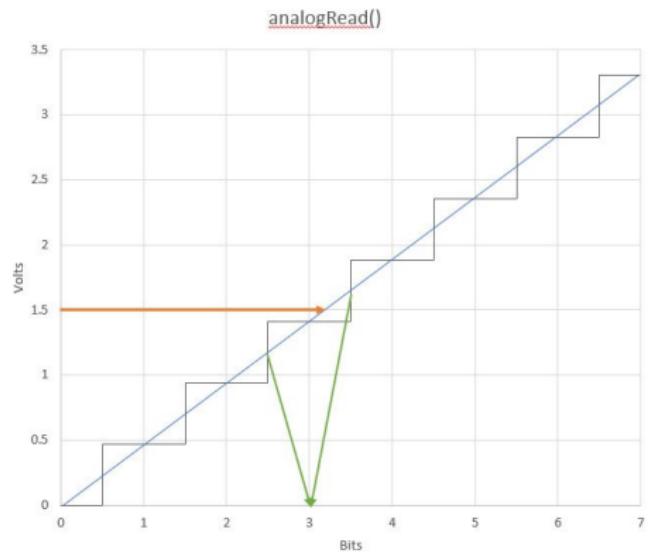
① L03_06_HelloNightLight

- The anode of the photodiode is connected to Pin A1. Note, unlike an LED, the cathode (short pin) of the photodiode is connected to 3.3V.
- The LED anode to Pin D14 (must be PWM).
- Using analogRead/digitalWrite, turn on the LED when the photodiode is in the "dark."
- Then modify your code to analogWrite to turn on the LED slowly as the room darkens.

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

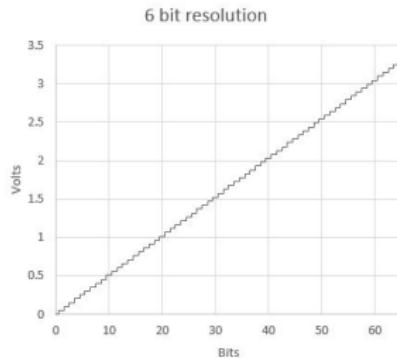
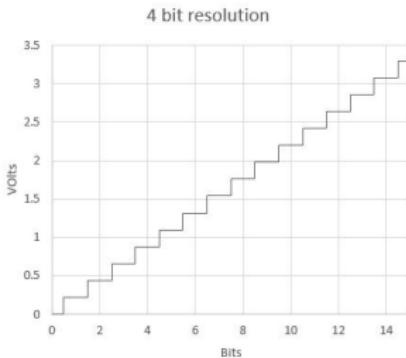
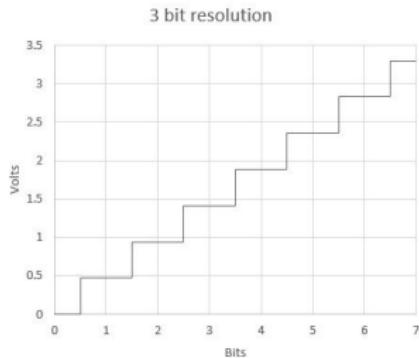


Analog Resolution - ADC





Analog Resolution - DAC

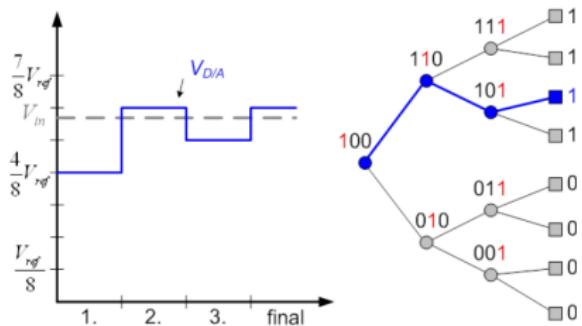
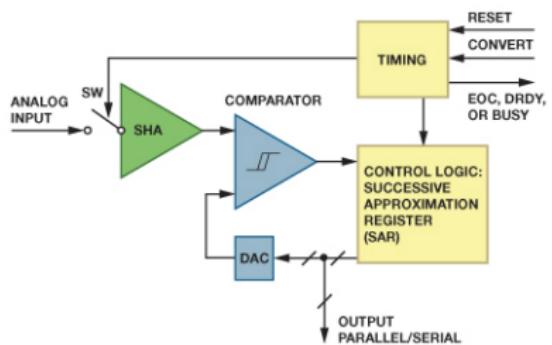


`analogWrite()` resolution can be modified between 2 and 31 bits.

```
1 analogWriteResolution(pin, bits);
```



Analog Resolution - ADC





Particle Publish

One of the advantages of the Particle is seamless publishing to the Cloud.

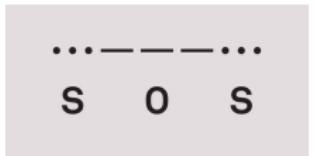
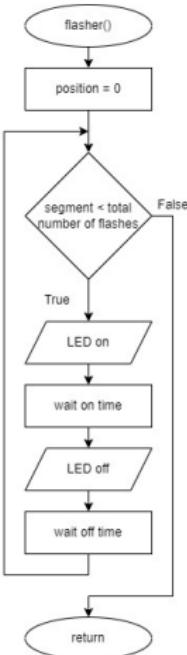
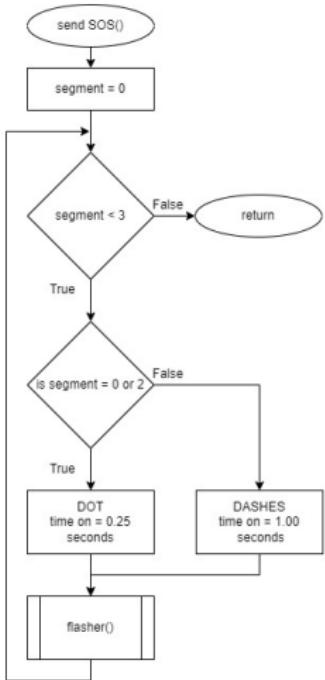
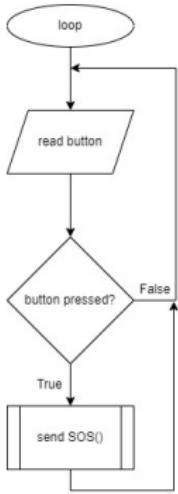
PARTICLE CLOUD			
EVENTS	VITALS	HEALTH CHECK	
		Search for events	ADVANCED
NAME	DATA	DEVICE	PUBLISHED AT
particle/device/update...	false	Lalonde	10/3/20 at 1:21:01 pm
spark/device/diagnos...	{"device": "network", "s...	Lalonde	10/3/20 at 1:21:00 pm
spark/device/app-hash	B665BEB9CD4ABE92IE3...	Lalonde	10/3/20 at 1:21:00 pm
Humidity	42.000000	Lalonde	10/3/20 at 1:20:58 pm
Pressure	29.780001	Lalonde	10/3/20 at 1:20:58 pm
Temperature	69.129997	Lalonde	10/3/20 at 1:20:58 pm
particle/device/update...	false	Lalonde	10/3/20 at 1:20:58 pm
particle/device/update...	true	Lalonde	10/3/20 at 1:20:58 pm
spark/device/last_reset	dfu_mode	Lalonde	10/3/20 at 1:20:58 pm
spark/status	online	Lalonde	10/3/20 at 1:20:58 pm

```
1 float temp, prs, hum;    // BME280 variables
2 String Temp, Prs, Hum;   // Strings to hold BME280 values
3
4 void loop() {
5     Temp = String(temp);
6     Prs = String(prs);
7     Hum = String(hum);
8     Particle.publish("Temperature", Temp, PRIVATE);
9     Particle.publish("Pressure", Prs, PRIVATE);
10    Particle.publish("Humidity", Hum, PRIVATE);
11 }
```

Modify L03_06_NightLight to publish the photodiode and LED values to the Particle Cloud once every 2 seconds.



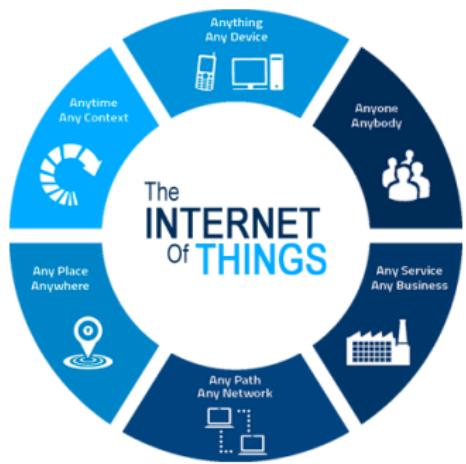
Optional Week 1 Review: L03_00_SOS



- Flowchart is in english, not code syntax
- Wire one button and one LED to your Photon2
- Declare the appropriate global variables and constants
- First function: void sos
- Second function: void flasher with parameters number of flashes, on time, off time between flashes
- Variables within the functions should be local, not global



Module 3 Review



● Learning Objectives

- ① Serial Monitor
- ② Buttons
- ③ Digital / Analog Inputs
- ④ Condition Statements
- ⑤ Particle Cloud Publishing

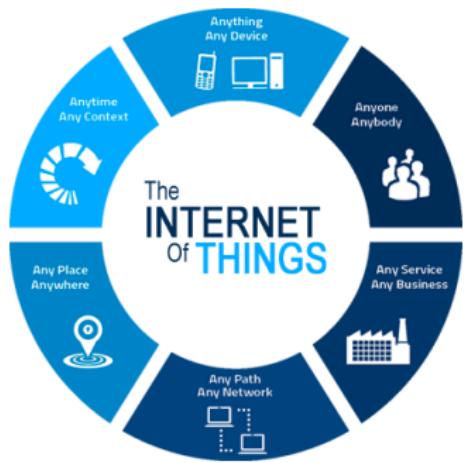
● Additional Items

- ① 3D Modeling Lesson 1 - Personalized Lego
- ② Quiz 2

Module 4 - NeoPixels



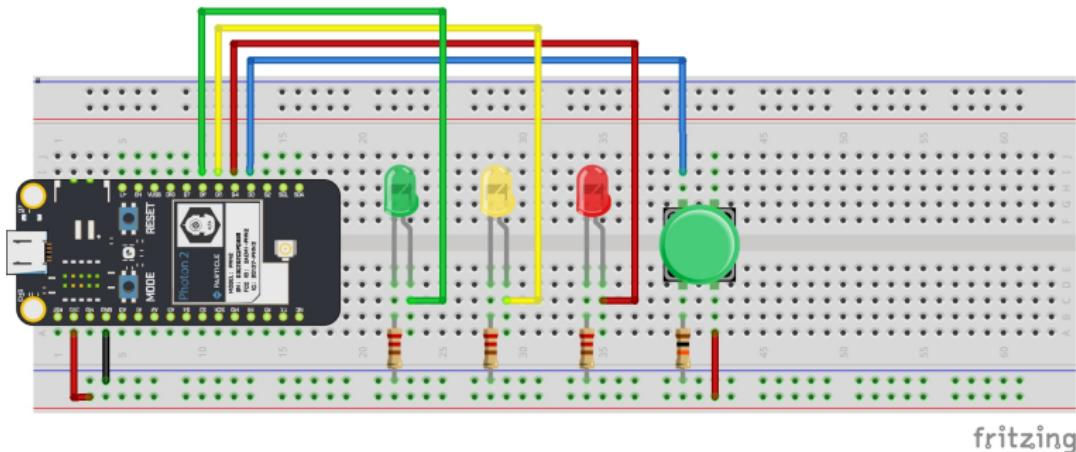
Module 4 Objectives



- Learning Objectives
 - ① Object Oriented Programming (OOP)
 - ② Soldering
 - ③ NeoPixels
 - ④ Working with Libraries
 - ⑤ Arrays
 - ⑥ Sort Algorithms
- Additional Items
 - ① Quiz 3



TrafficLight Board Setup



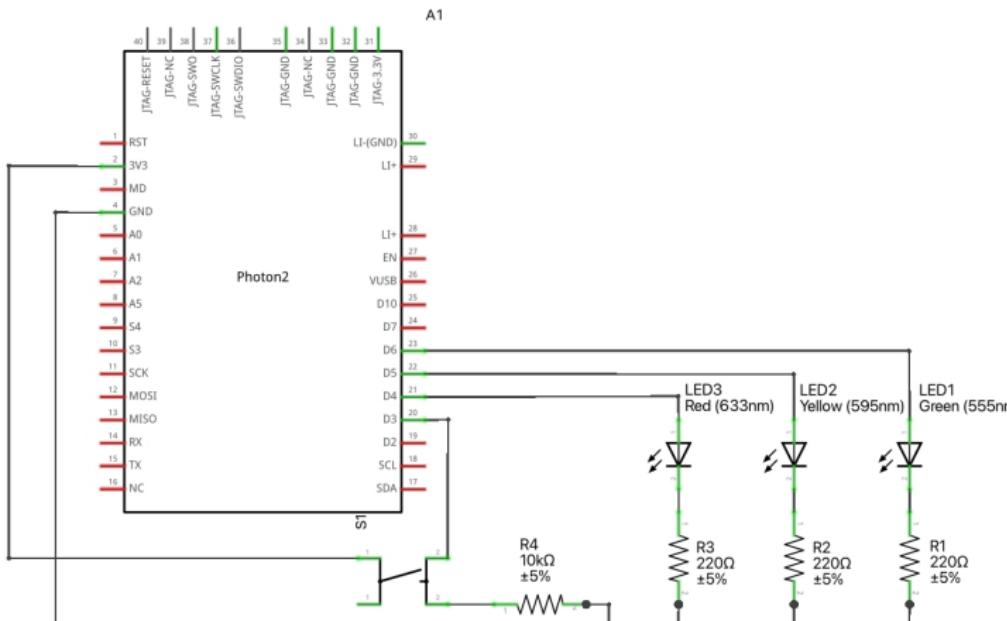
fritzing

PINS:

- LEDs: Green (D6), Yellow (D5), Red (D4) with 220Ω resistors
- Button: D3 with $10k\Omega$ pulldown resistor



TrafficLight Board Schematic



fritzing

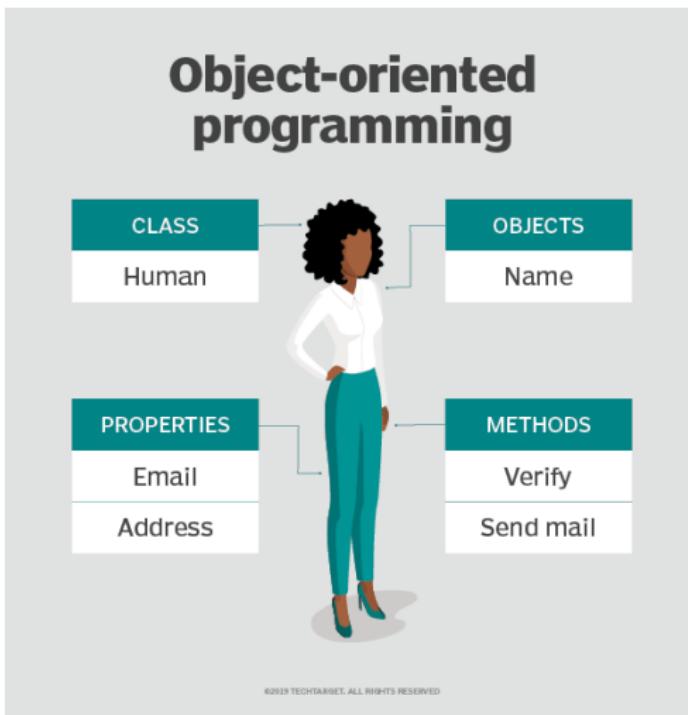


Smart Communities



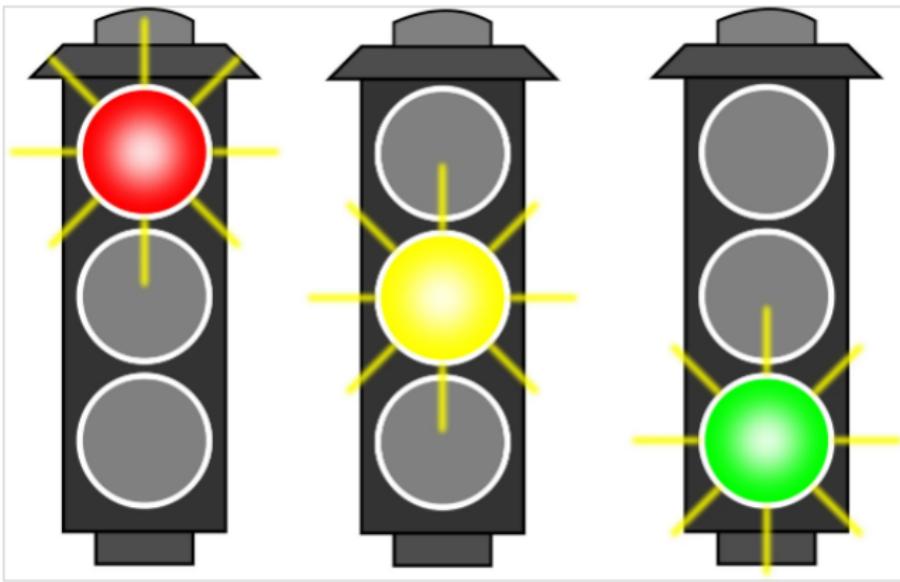


Objects





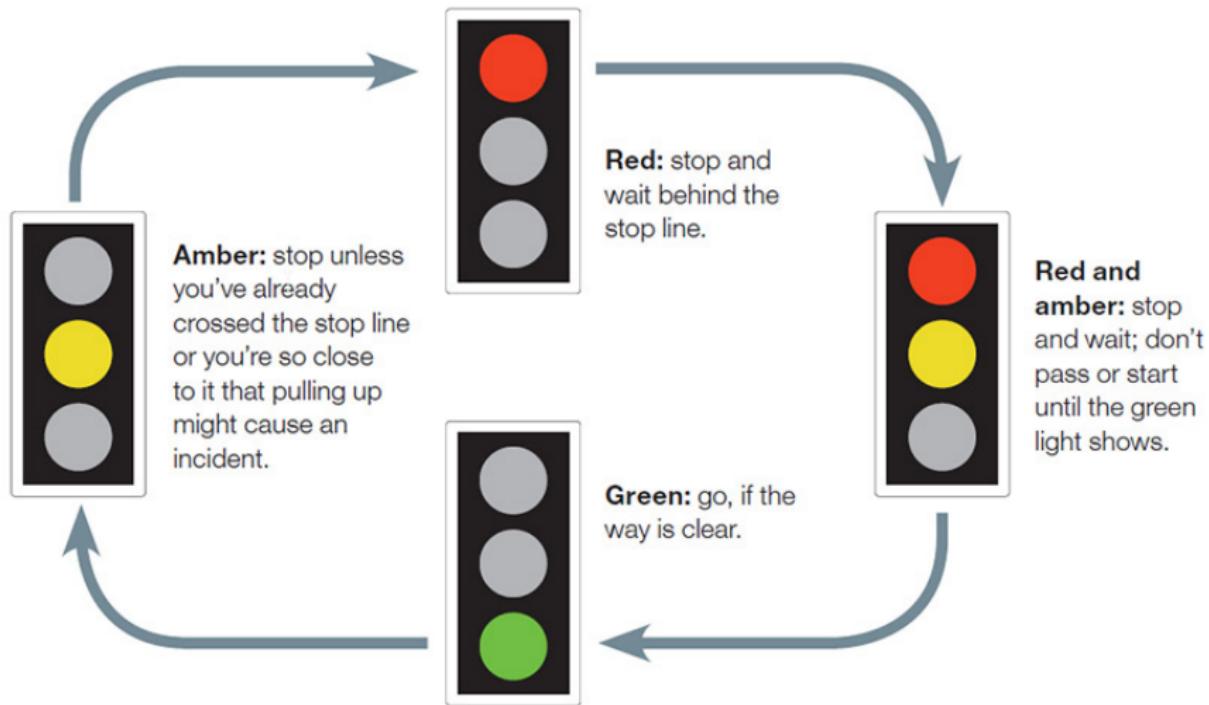
Traffic Light



Let's use the traffic light to build our own Objects.



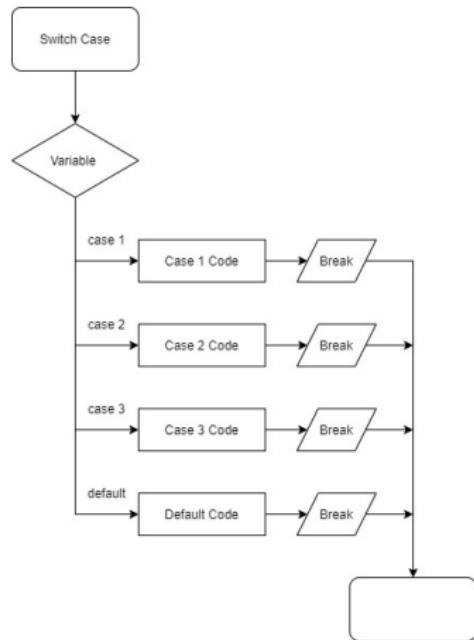
State Machine - Traffic Lights, British Style





SWITCH...CASE syntax - multiple IFs

```
// SWITCH...CASE syntax
switch (variable) {
    case constant1:
        // statements
        break;
    case constant2:
        // statements
        break;
    case constant3:
        // statements
        break;
    default:
        // statements
        break;
}
```



The variable is compared to the constants and the applicable code is called. If variable doesn't match any of the constants, then the default case is called.



Enumeration (enum)

The C-language has a user-defined datatype, enum, which allows the user to create a variable with various names for each of its states.

- Within the enum declaration descriptive tags are used.
- Then the compiler assigns the tags an integer value.

```
1 // Datatype State: the four traffic light states
2 enum State{
3     GREEN,
4     YELLOW,
5     RED,
6     RED_YELLOW
7 };    //note the ; after the }
```

The compiler treats enum as your personal variable type. For example, the enum variable (e.g., State) can now be used within switch...case statements.



Preprocessor commands

The C-compiler preprocessor executes the `#` commands before converting the program into code the microcontroller can understand.

We have previously used the `#include` preprocessor command. Now, we will learn a few more:

```
1 #ifndef _BUTTON_H_    //if not defined, then execute the rest of code
2
3 #define _BUTTON_H_ //define the label
4
5 // Place your Header.h code here
6
7#endif // _BUTTON_H_
```

- `#ifndef` - if the label is not defined, then execute code until `#endif`
- `#define` - define the label
 - the `#define` label can be set to a value
 - the compiler then replaces the label with the value where ever it sees it meaning it is similar to `const <datatype> = <value>`.
 - NOTE: we will use the CONSTANT and not the `#define`



Soldering

Soldering is one of the most fundamental skills needed to construct IoT devices.



- Solder the Noun: the alloy (a substance composed of two or more metals) that typically comes as a long, thin wire in spools or tubes
- Solder the Verb: to join together two pieces of metal in what is called a solder joint.

So, we solder with solder!



Soldering

- Lead vs Lead-free: Traditionally, solder was composed of mostly lead (Pb), tin (Sn), and a few other trace metals. However, lead is hazardous in large quantities.
 - Lead solder has superior properties - lower melting point, flows well, less internal flaws after cooling.
 - Lead-free solder has a higher melting point and thus needs assistance to flow. Many have flux core, a chemical that aids in the flowing.
- Solder flux: Flux is a chemical cleaning agent used before and during the soldering process of electronic components. The flux also protects the metal surfaces from re-oxidation during soldering and helps the soldering process by altering the surface tension of the molten solder.





Solder Irons



- Solder tips - the tip transfers heat, raising the temperature of the metal components to the melting point of the solder. They come in a variety of shapes and sizes.
- Wand - the wand holds the tip and may have a separate base. The wand controls the temperature of the tip. The temperature range depends on the type of solder.
 - Lead solder - 600°-650°F (316°-343°C)
 - Lead-free solder - 650°-700°F (343°-371°C)
- Brass Sponge - During soldering the tip will start to oxidize, it will change color and less readily accept solder. The brass sponge will reduce buildup. Alternatively, a wet sponge can be used.



Solder Tip Care



CLEANING YOUR TIPS

To clean your tips, use either **brass** or **stainless steel wool**. Brass wool is softer and less abrasive, while the harder stainless steel wool has a longer life. After cleaning, immediately wet the tip with fresh solder to prevent oxidation.

TINNING YOUR TIPS

Tinning stops your tips from oxidizing by creating a **protective layer** between the air and the iron. Preventing oxidation through tinning **extends the life** of your tips.



OXIDIZED TIP



TINNED TIP

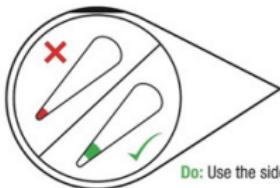


Properly Storing Tips

If storing your tips for an extended period, you should **clean** and **tin** them before putting them away, which will help prevent them from oxidization. After letting them cool, you may also want to **store them in a sealed container** to further protect them from oxidation, humidity and contamination.



Good vs Bad Solder Joints



Don't: Use the very tip of the iron.

Do: Use the side of the tip of the iron, "The Sweet Spot."



Do: Touch the iron to the component leg and metal ring at the same time.



Do: While continuing to hold the iron in contact with the leg and metal ring, feed solder into the joint.



Don't: Glob the solder straight onto the iron and try to apply the solder with the iron.



Do: Use a sponge to clean your iron whenever black oxidation builds up on the tip.



A

Solder flows around the leg and fills the hole - forming a volcano-shaped mound of solder.



B

Error: Solder balls up on the leg, not connecting the leg to the metal ring.
Solution: Add flux, then touch up with iron.



C

Error: Bad Connection (i.e. it doesn't look like a volcano)
Solution: Flux then add solder.



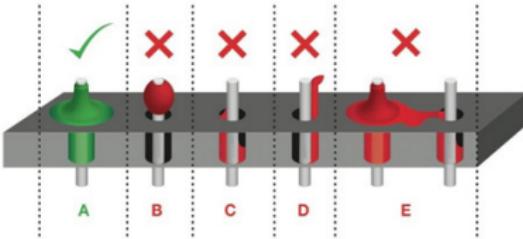
D

Error: Bad Connection...and ugly...oh so ugly.
Solution: Flux then add solder.



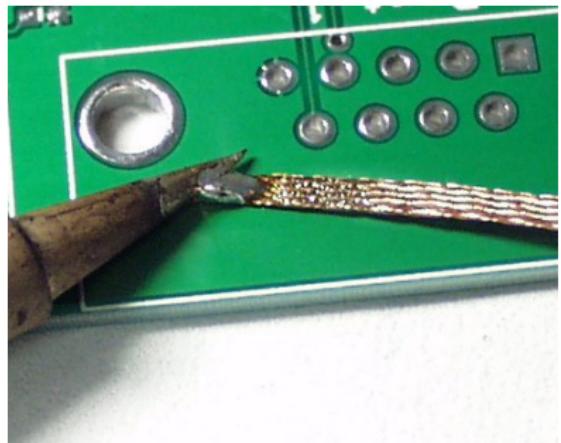
E

Error: Too much solder connecting adjacent legs (aka a solder jumper).
Solution: Wick off excess solder.

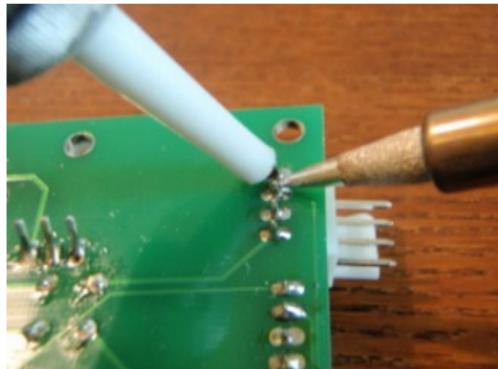




Desoldering



Solder Wick



Desoldering Pump



Generating Random Numbers

```
1  /*
2   * The random() function generates pseudo-random
3   * numbers.
4   *     random(min,max)
5   *     random(max)      //assumes min = 0
6   * returns a number between min and max-1
7   */
8
9 // print a random number from 0 to 299
10 randomNumber = random(300);
11 Serial.printf("The number is = %i \n",randomNumber);
12
13 // print a random number from 10 to 19
14 randomNumber = random(10, 20);
15 Serial.printf("The number is = %i \n",randomNumber);
```



Nested Statements



- Loops and conditions can be nested within each other
- A nested loop is a loop within a loop, an inner loop within the body of an outer one. How this works is that the first pass of the outer loop triggers the inner loop, which executes to completion. Then the second pass of the outer loop triggers the inner loop again. This repeats until the outer loop finishes.
- The break command can be used to exit a loop before completion

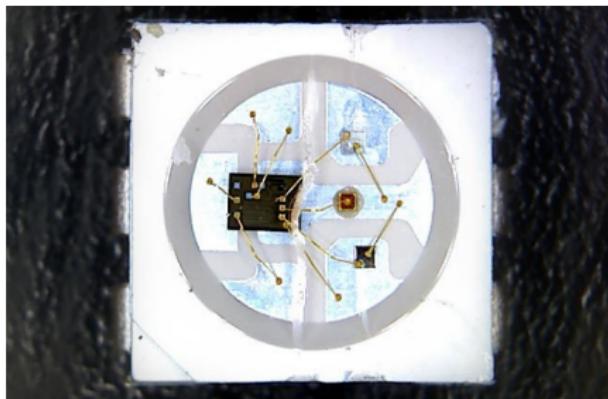


Nested For Loops

```
1 int tens;
2 int ones;
3
4 // Nested FOR Loops
5 for(tens=0;tens<10;tens++) {
6     for(ones=0;ones<10;ones++) {
7         Serial.printf("Combining %i(tens) and %i(ones) gives %i%i\n",tens,ones,tens,ones);
8     }
9 }
10
11 // An IF nested in Nested FOR Loops
12 for(tens=0;tens<10;tens++) {
13     for(ones=0;ones<10;ones++) {
14         if(tens != ones) {
15             Serial.printf("Combining %i(tens) and %i(ones) gives %i%i\n",tens,ones,tens,ones);
16         }
17     }
18 }
19
20 // Using break to break out of a loop
21 for(tens=0;tens<10;tens++) {
22     for(ones=0;ones<10;ones++) {
23         Serial.printf("Combining %i(tens) and %i(ones) gives %i%i\n",tens,ones,tens,ones);
24         if((tens+ones) == 10) {
25             break;
26         }
27     }
28 }
```



NeoPixels

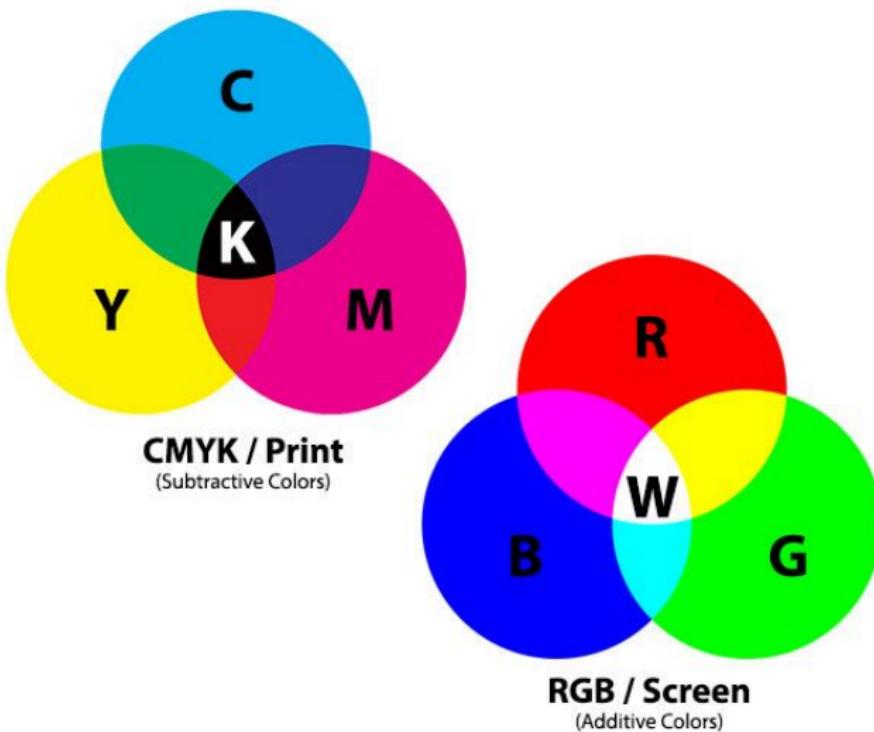


NeoPixels are:

- Addressable RGB LEDs based on the WS2812 (or WS2811) LED/drivers.
- They come as individual pixels, in strips, in matrices, rings, etc.
- They can be programmed via your microcontroller to create a wide array of effects and animations.

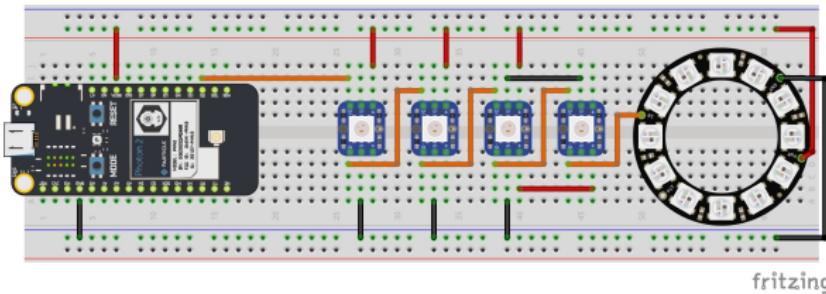


CYMK vs RGB Colors



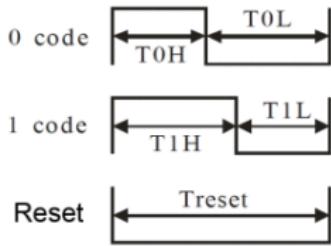


NeoPixel Programming

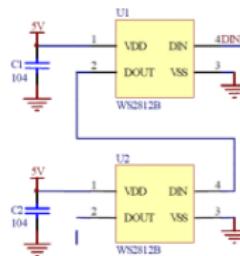


fritzing

WS2812 Protocol

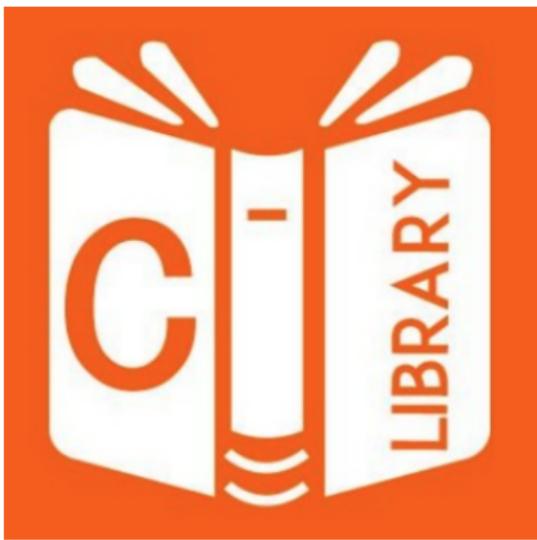


LED-Chain





Installing Libraries

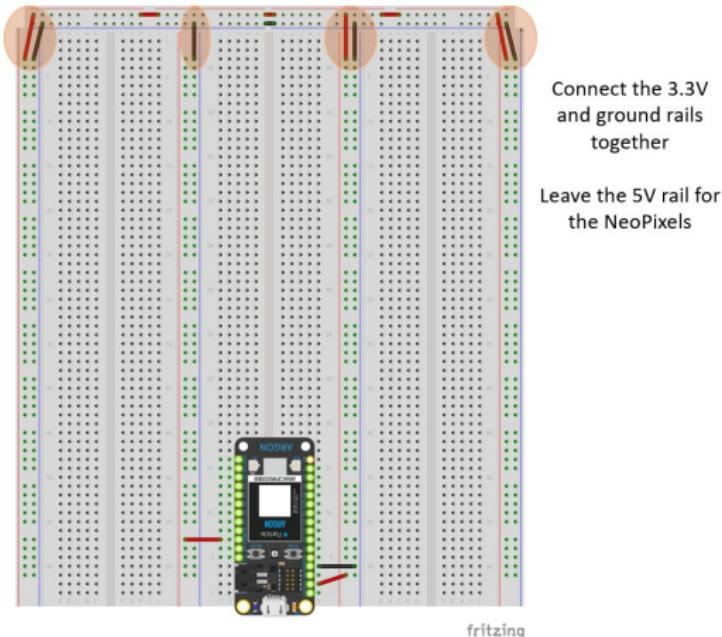


Using the Command Palette within VSCode:

- **ctrl-shift-p → Particle: Find Libraries**
- **ctrl-shift-p → Particle: Install Library**

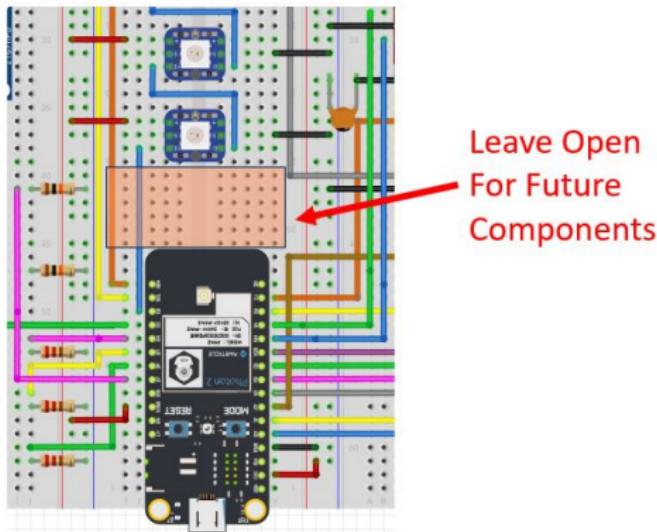


Move to Big Breadboard





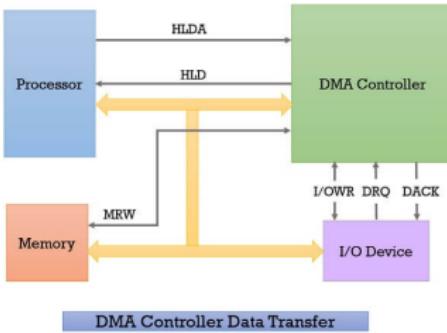
Leave Space for Future Components





Direct Memory Access (DMA)

Many microcontrollers interface with Neopixels through any GPIO using the bit banging⁵ approach.



The Photon2 has some bit banging limitations, so the Neopixels need to be controlled through DMA using either pin D2 (SPI1) or D15 (SPI⁶).

⁵bit banging is a "term of art" for any method of data transmission that employs software as a substitute for dedicated hardware to generate transmitted signals or process received signals.

⁶SPI Bus will be covered in detail later in the course



Using NeoPixel Class and Methods

```
1 #include <neopixel.h>
2
3 const int PIXELCOUNT = 16; // Total number of NeoPixels
4
5 Adafruit_NeoPixel pixel(PIXELCOUNT, SPI1, WS2812B); //declare object
6 /* Argument 1 = Number of pixels
7 * Argument 2 = GPIO pin number
8 * Argument 3 = Pixel type flags, add together:
9 * Use:
10 *   WS2811      // 400 KHz datastream (NeoPixel)
11 *   WS2812      // 800 KHz datastream (NeoPixel)
12 *   WS2812B     // 800 KHz datastream (NeoPixel)
13 *   WS2813      // 800 KHz datastream (NeoPixel)
14 *   WS2812B2    // 800 KHz datastream (NeoPixel)
15 *   SK6812RGBW // 800 KHz datastream (NeoPixel RGBW)
16 */
17 void setup() {
18   pixel.begin();
19   pixel.setBrightness(bri);                      // bri is a value 0 - 255
20   pixel.show(); //initialize all off
21 }
22
23 void loop() {                                // n is the pixel number being set
24   pixel.setPixelColor(n, red, green, blue); // red,green,blue = 0 - 255
25   pixel.setPixelColor(n, color);           // hex code 0x000000 - 0xFFFFFFFF
26   pixel.show();                            // nothing changes until show()
27   pixel.clear();                          // even clear() needs a show()
28   pixel.show();                          // even clear() needs a show()
29 }
```



Assignment: NeoPixels



- Notebook: flowchart
- Notebook: schematic
- Fritzing using BigBreadBoard.fzz
- Wire your circuit
- Write the code

① L04_01_neoPixel

- Using FOR loop and individual R/G/B, light up 46 pixels; small delay between.

② L04_02_colorHeader

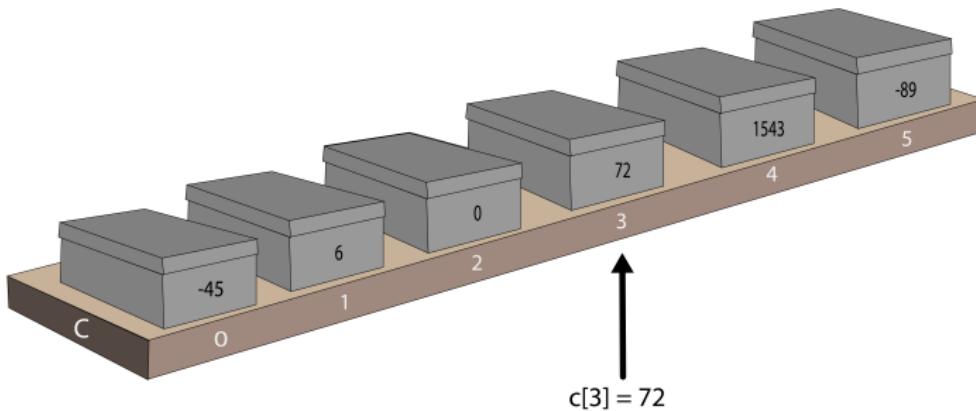
- Implement a header file that contains the pixel colors.

③ L04_03_neoStrip, use setPixelColor() to:

- Send a pixel of a random color down and back on the strip.
- Send a pair of Maize and Blue lights down the strip.
- Send pixels in different directions at the same time.
- Have the pixels move at different speeds.



Arrays



- Syntax: datatype var[] = {element 1, element 2, element 3};
- Example: int c[] = {-45, 6, 0, 72, 1543, -89}



Using Arrays

```
1 int myInts[6];
2 int myPins[] = {2, 4, 8, 3, 6};
3 int mySensVals[6] = {2, 4, -8, 3, 2};
4 char message[6] = "hello";
5
6 void loop() {
7     mySensVals[0] = 10; //assign value to array
8     x = mySensVals[4]; //retrieve value from array
9     for (i = 0; i < 5; i = i + 1) {
10         Serial.printf("Pin %i selected \n", myPins[i])
11         ;
12     }
13 }
```

Note: An array index starts at 0 (not 1).



Assignment: NeoPixels (continued)



- ① Using Illustrator and the Epilog, make an acrylic neopixel ring holder.
 - ② Add to L04_03_neoStrip, use `setPixelColor()` to implement functions:
 - Light the strip up as a rainbow.
 - ③ L04_04_pixelFill, create a function:
 - Create a function called `pixelFill` with three parameters (start pixel, an end pixel, and hex color) that lights up a segment of the pixel strip.
 - Use `pixelFill()` to light 7 segments of your strip in the colors of the rainbow.
 - ④ L04_05_pixelCTRL (extra credit)
 - Use the button to change the color.
 - Use the potentiometer to change how many pixels are lit up (0 to 45)
- Notebook: flowchart
 - Write the code



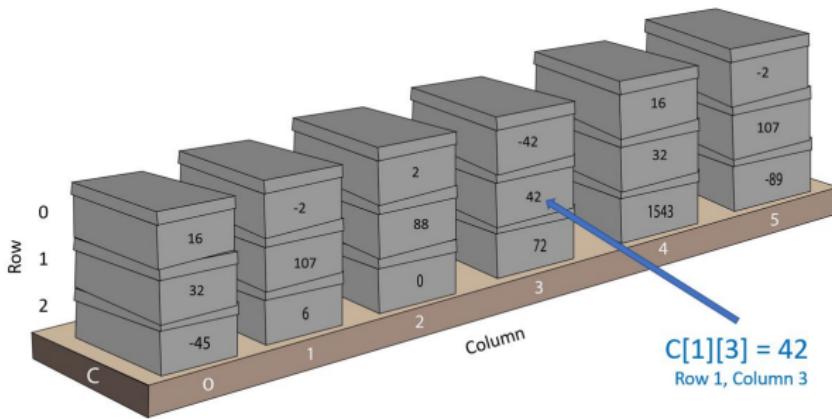
RandomSeed()

- The "pseudo" in pseudo-random indicates it is not truly random.
- randomSeed() initializes the pseudo-random number generator causing it to start at an arbitrary point in its random sequence. This sequence, while very long, and while appearing random, is always the same.
- If it is important for a sequence of values generated by random() to differ, on subsequent executions, use randomSeed() to initialize the random number generator with a fairly random input, such as an analogRead() on an unconnected pin.

```
1 // Leave an Analog Input (A0) floating
2 pinMode(A0, INPUT);
3 randomSeed(analogRead(A0));
4
5 // print a random number hex color value
6 randNumber = random(0x0000,0xFFFFFFF);
7 Serial.printf("My color is 0x%06X \n",randNumber);
```



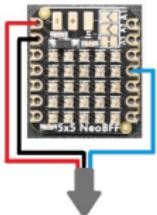
2-dimensional arrays



- Declare Array: `int c[3][6] = {{16,-2,2,-42,16,-2},{32,107,88,42,32,107},{-45,6,0,72,1543,-89}};`
- Set a Cell: `c[1][3] = 42;`
- Access a Cell: `x = c[1][3]; → x = 42`



Neopixel Matrix



- RED: 5V
- BLACK: GND
- BLUE: SPI1 (D2 Pin)

```
1 #include "Particle.h"
2 #include <neopixel.h>
3 #include <Colors.h>
4
5 const int PIXELCOUNT = 25;
6 Adafruit_NeoPixel pixel(PIXELCOUNT, SPI1, WS2812B);
7 const int PIXELMAP[5][5] = {{ 0, 1, 2, 3, 4},
8                             { 5, 6, 7, 8, 9},
9                             {10,11,12,13,14},
10                            {15,16,17,18,19},
11                            {20,21,22,23,24}};
12 void setup() {
13   pixel.begin();
14   pixel.clear();
15   pixel.setPixelColor(PIXELMAP[2][2],purple); //light up middle pixel
16   pixel.show();
17 }
```



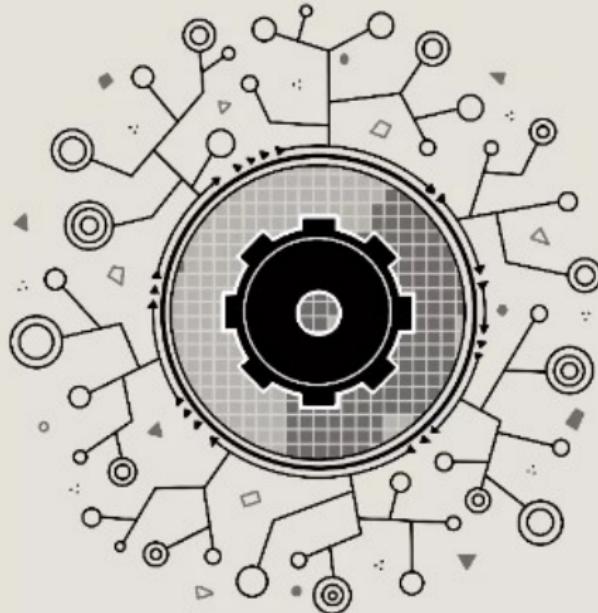
Assignment: L04_06_NeoMatrix



- Notebook: flowchart
- Notebook: Schematic
- Fritzing
- Wire Circuit
- Write the code
- Use a single "for loop" to create an "X" on the matrix
- Create a sequence of three solid squares using nested "for loop"
 - Center dot only
 - 9 dots in the center
 - All 25 dots
- Draw a smiley face using a bitmap matrix and the PIXELMAP
 - Bitmap matrix is a 5x5 that has 0xFF where you want a pixel and a 0x00 where no pixel
 - Use the bitmap matrix to set the color for each PIXELMAP pixel.
- EXTRA: Create a sequence of three hallow squares (outline only)



Algorithms



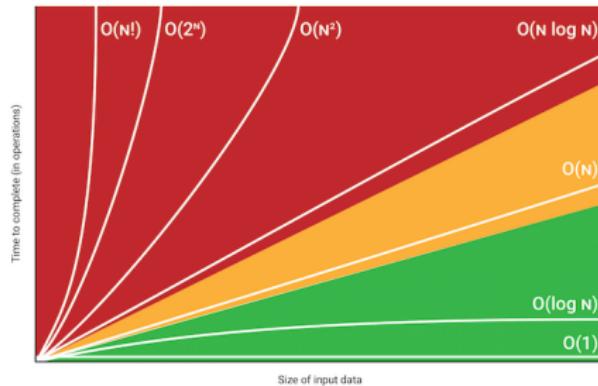
Algorithm

[al-gə-ri-thəm]

A set of instructions for solving a problem or accomplishing a task.



Big O Notation



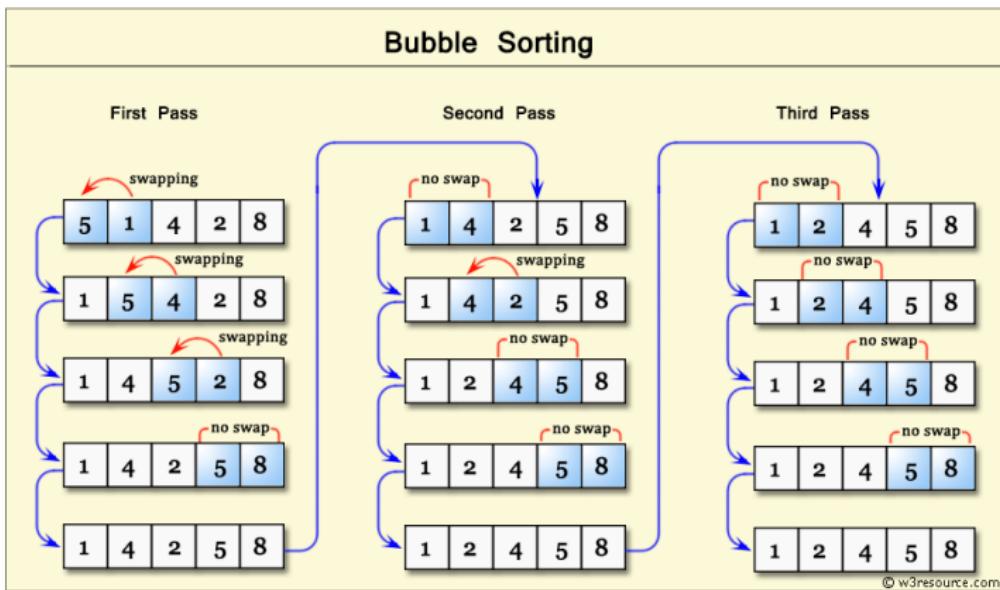
Big O notation is a way to describe the speed or complexity of a given algorithm.

- Big O notation tells the number of operations an algorithm will make.
- It gets its name from the literal "Big O" in front of the estimated number of operations.
- Big O establishes a worst-case run time



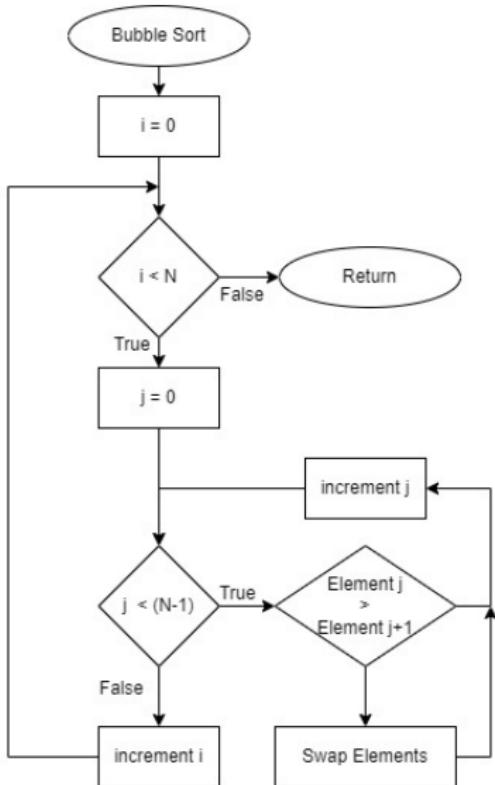
Bubble Sort

Bubble Sorting





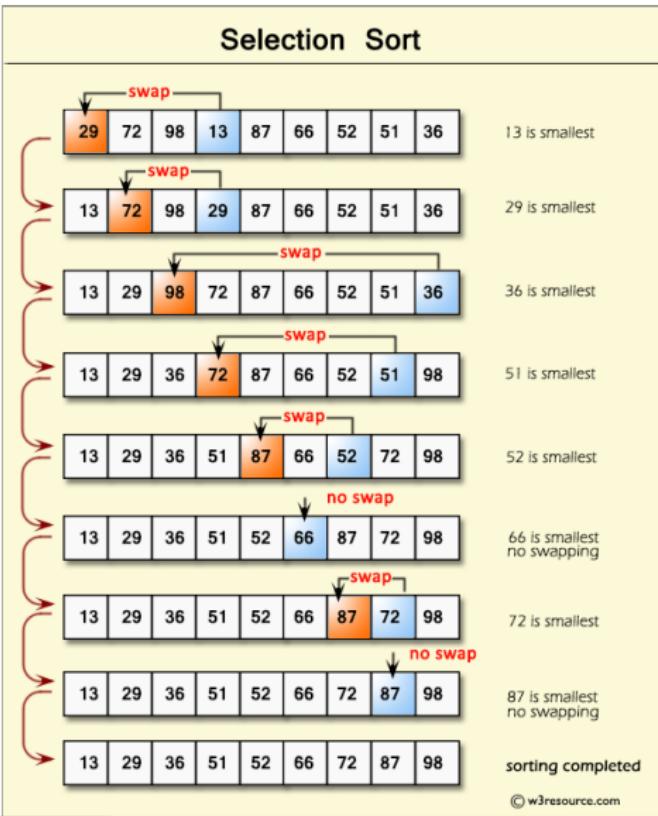
Bubble Sort Algorithm - $O(n^2)$



- Larger elements are swapped (one-by-one) with smaller ones (i.e., they float to the top)
- Takes $O(n^2)$ iterations as there is a $(N - 1)$ loop nested in a N loop.

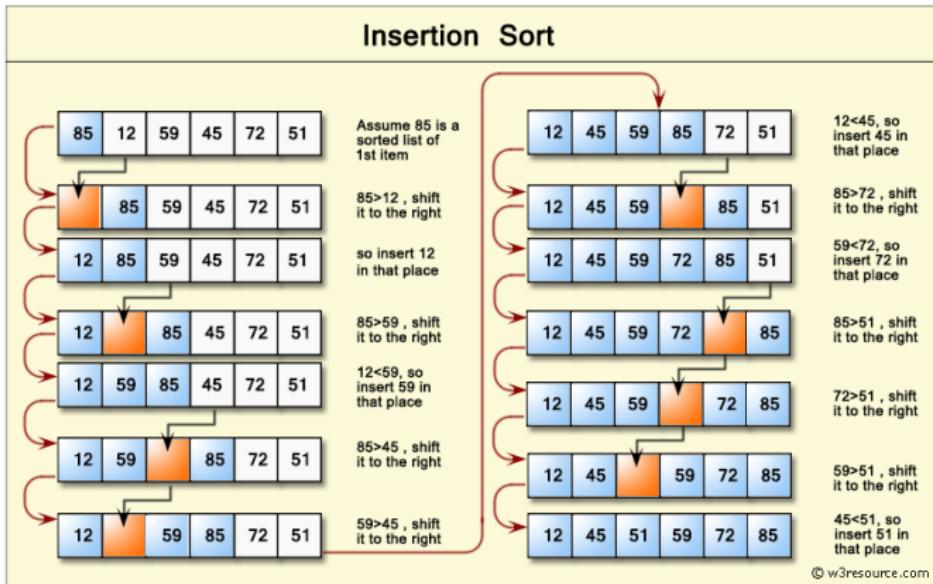


Selection Sort



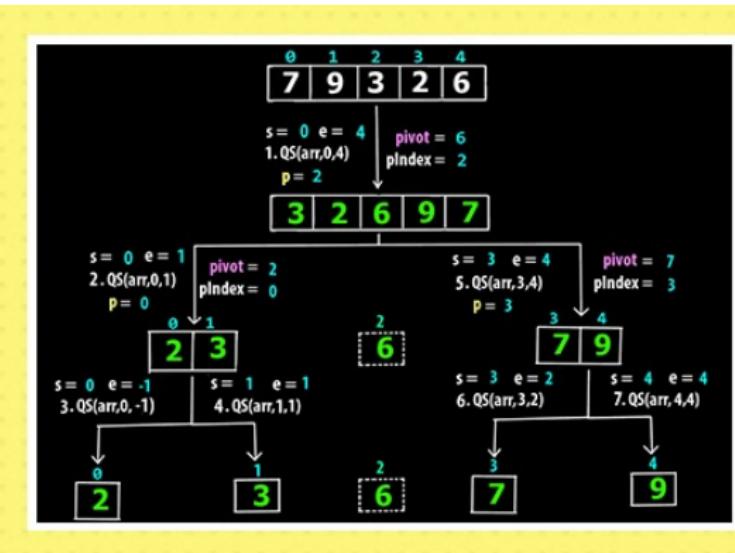


Insertion Sort





Quick Sort

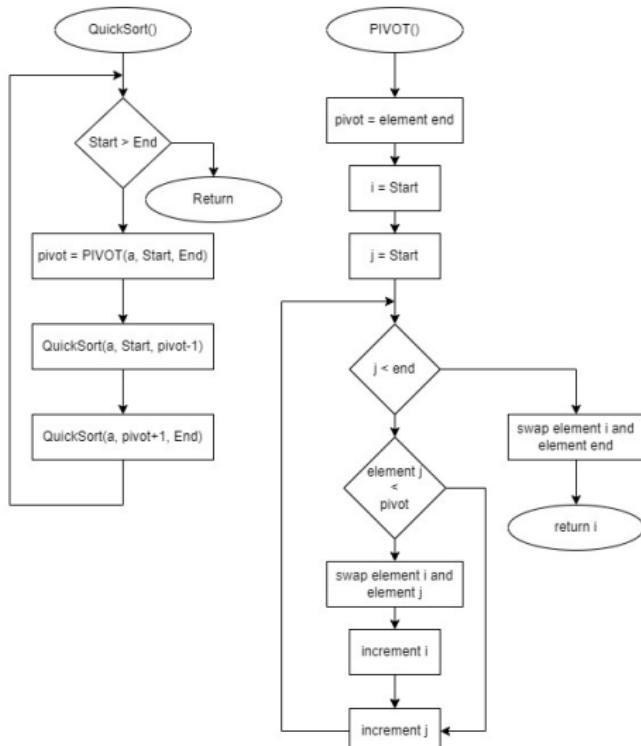


QUICK SORT ALGORITHM

```
QuickSort(arr[], s, e)
{
    if(s < e)
    {
        p = Partition(arr[], s, e)
        QuickSort(arr[], s, (p-1))
        QuickSort(arr[], (p+1), e)
    }
}
```



Quick Sort Algorithm - $O(n \log(n))$



- Any pivot point is selected (in this case, the last element)
- Smaller elements are put to the left of the pivot, larger to the right.
- Each side of the pivot is then sorted using the same method. This is called recursion.
- This continues until everything is sorted.
- In general, this takes $O(n \log(n))$ iterations



Assignment: L04_07_sorting

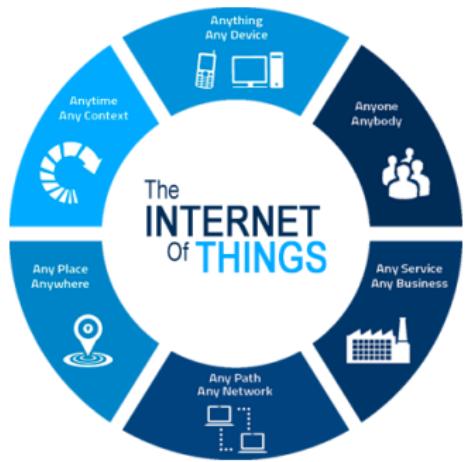


- Notebook: flowchart
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- Randomly fill an array of length equal to number of neopixels with colors from blue to red.
- Implement a function for the bubble sort that displays the change in the array after each iteration.
- Implement either the selection or insertion sort on a new random array
 - start with a flow chart in your notebook
 - then work on the code
- (Optional) implement the quicksort



Module 4 Review



● Learning Objectives

- ① Object Oriented Programming (OOP)
- ② Soldering
- ③ NeoPixels
- ④ Working with Libraries
- ⑤ Arrays
- ⑥ Sort Algorithms

● Additional Items

- ① Quiz 3

Module 5 - Encoders

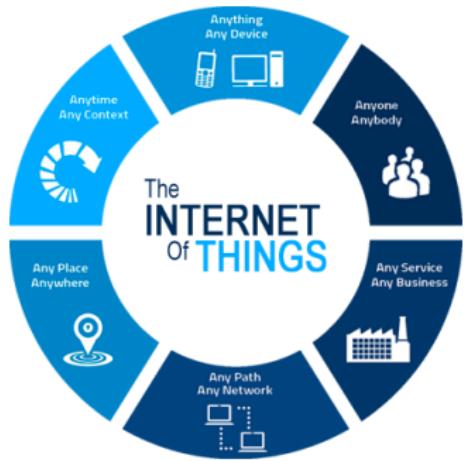


IoT Humor





Module 5 Objectives



- Learning Objectives
 - ① Encoders
 - ② Capacitors
 - ③ Oscilloscopes
 - ④ Low Pass Filters
- Additional Items
 - ① 3D Modeling Lesson 2 - Spur Gear



Internal State Variables

Internal state variables are variables that allow the program to keep track of conditions, settings, or states within the program.

```
1 #include "Buttons.h"
2 Button wallButton(D10);
3
4 const int LEDPIN = D7;
5 bool onOff; //internal state variable that keeps track of on or off
6
7 void setup() {
8   pinMode(LEDPIN,OUTPUT);
9 }
10
11 void loop() {
12   if (wallButton.isClicked()) { // if button clicked toggle onOff
13     onOff = !onOff;
14   }
15
16   if (onOff) { // use onOff to control LED
17     digitalWrite(LEDPIN,HIGH);
18   }
19   else {
20     digitalWrite(LEDPIN,LOW);
21   }
22 }
```

onOff is an internal state variable: the button controls the onOff variable and then the onOff variable controls the LED

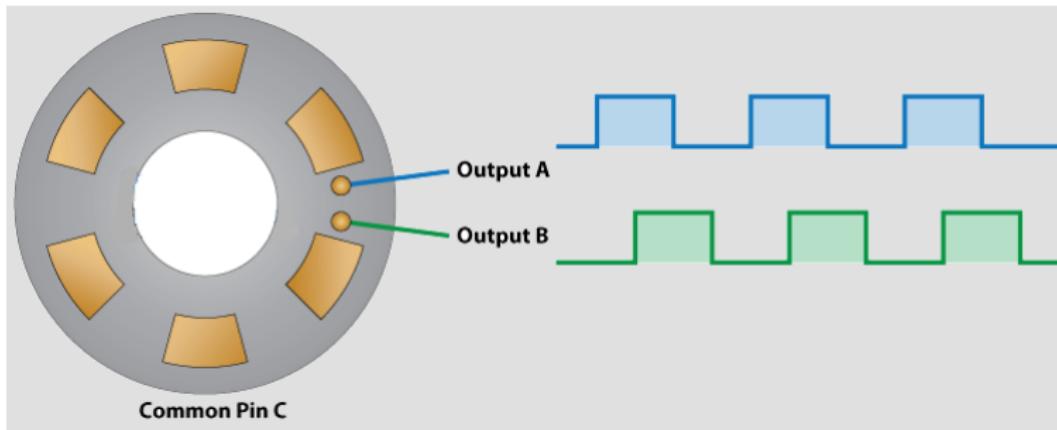


Avoiding Delays - Keeping track of previous time

```
1 void loop() {  
2     //run constantly  
3     currentTime = millis();  
4  
5     //run once per second  
6     if((currentTime-lastSecond)>1000) {  
7         lastSecond = millis();  
8         Serial.printf(".");  
9     }  
10  
11    //run once per minute  
12    if((currentTime-lastMinute)>60000) {  
13        lastMinute = millis();  
14        Serial.printf("\nMinute\n");  
15    }
```



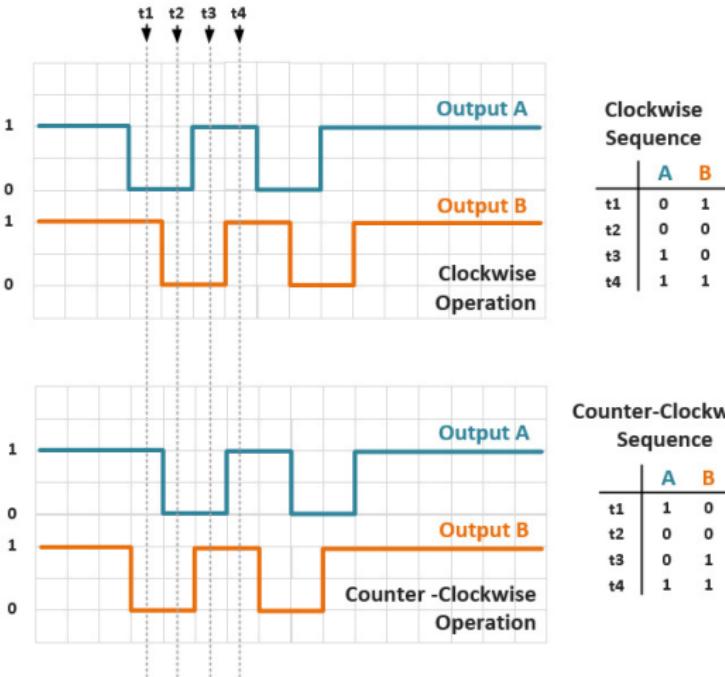
Encoders



The Common Pin C is connected to all of the "pads." If C is connected to Ground, then the voltage of A and B go to ground when the pad touches the respective A/B "bump." The voltage of A and B are interpreted by the microcontroller to determine when/how the encoder is moved.



Encoders



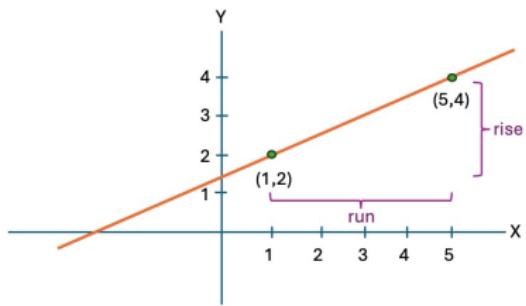


The Encoder Class

```
1 #include <Encoder.h>
2 Encoder myEnc(PINA, PINB);
3 // The "c" pin on the encoder is connected to GND
4
5 void setup() {
6 }
7
8 void loop() {
9     // read encoder position
10    position = myEnc.read();
11
12    // set encoder to a position
13    myEnc.write(maxPos);
14 }
```



REMINDER: Linear Conversion



$$y = mx + b$$

where m is slope and b y-intercept.

For example, given two points:

- $(x_1, y_1) = (1, 2)$
- $(x_2, y_2) = (5, 4)$

Find slope

- $m = \frac{\text{rise}}{\text{run}} = \frac{4-2}{5-1} = \frac{1}{2}$

Find y-intercept

- $y_1 = m * x_1 + b$
- $b = y_1 - (m * x_1)$
- $b = 2 - (\frac{1}{2} * 1) = 1\frac{1}{2}$



Assignment: Encoders



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① L05_01_encoder

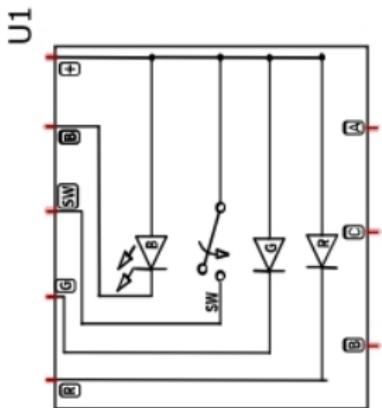
- Implement the encoder using Pins D8 and D9
- Display the encoder position to the Serial Monitor, but only when encoder is moved.

② L05_02_NeoPixel

- The encoder has 96 positions. Use the Linear Conversion to find the equation that maps the encoder input to 16 NeoPixels.
- Use `myEnc.write()` to Bound the input in a way that:
 - If `myEnc.read() > 95`, it is set back to 95
 - If `myEnc.read() < 0`, it is set back to 0
- Use the encoder to light up the NeoPixels



Encoder - LEDs and Button



```
void setup()
```

- pinMode(LEDPIN,OUTPUT);
- pinMode(SWPIN,INPUT_PULLDOWN);

```
void loop()
```

- digitalWrite(LEDPIN,LOW);
- switchState = digitalRead(SWPIN);

fritzing

The encoder has a Red, Green, and Blue LED, as well as a Switch (technically a Button), that act like discrete components and are not associated with the Encoder.h library. Note, the LEDs are active low (the pins need to be set to ground to activate the light).



Assignment: Encoders



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① L05_03_encoder_switch

- Connect the encoder switch and LEDs.
- Use the switch to turn on/off the NeoPixels.
- Set encoder LED to red for off and green for on.
- Disable turning the encoder when off.

② L05_04_rainbow

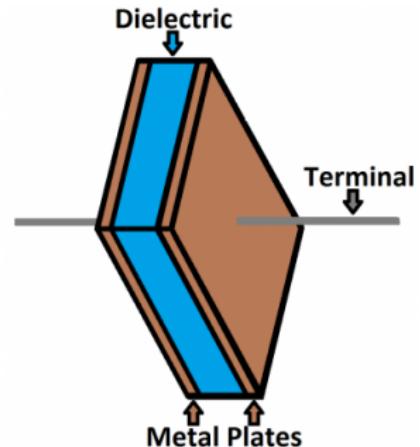
- Use a button to cycle the NeoPixel ring colors through the colors of the rainbow; one color change each time button is pressed.
- Refactor the code using IoTClassroom_CNM → Button.h and the .isClicked() method.



Capacitors

A capacitor is created out of two metal plates and an insulating material called a dielectric. The metal plates are placed very close to each other, in parallel, but the dielectric sits between them to make sure they don't touch.

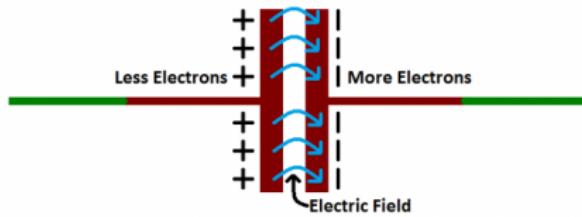
- The dielectric can be made out of all sorts of insulating materials; paper, glass, rubber, ceramic, plastic, or anything that will impede the flow of current.
- The plates are made of a conductive material; aluminum, tantalum, silver, or other metals.





Capacitors

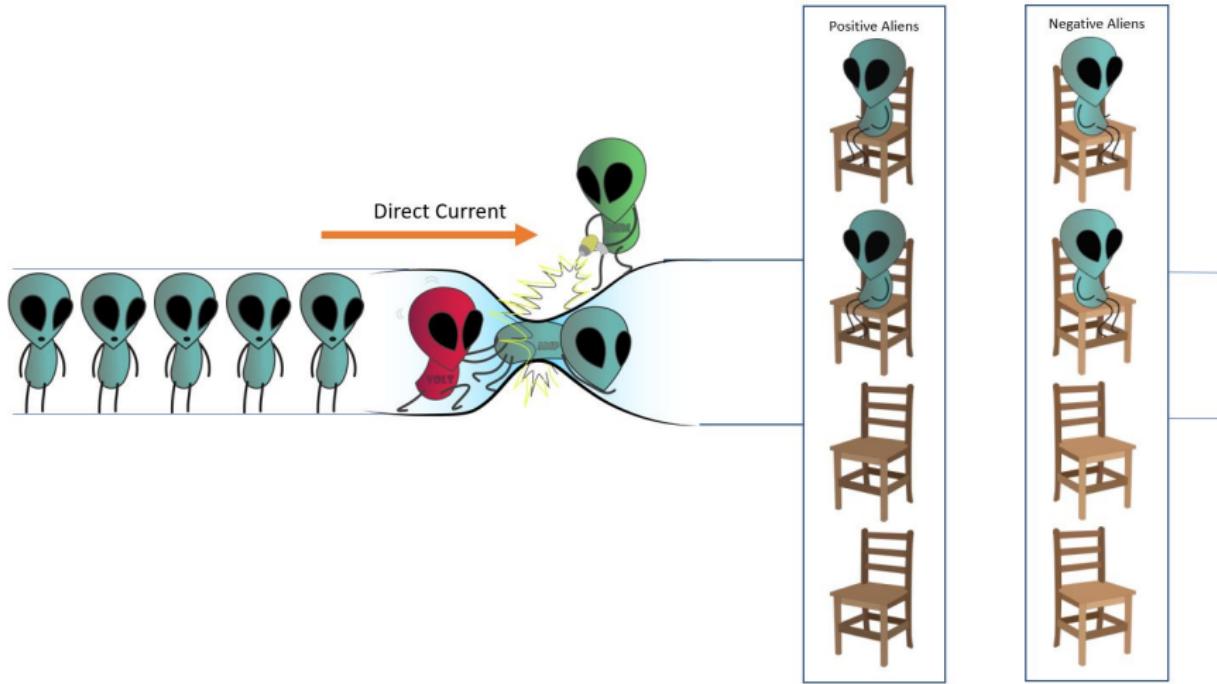
When current flows into a capacitor, the charges get "stuck" on the plates because they cannot get past the insulating dielectric. Electrons build up on one of the plates, and it becomes overall negatively charged. The large amount of negative charges pushes away like charges on the other plate, making it positively charged.



The stationary charges on these plates create an electric field, which influences electric potential energy and voltage. When charges group together on a capacitor like this, the capacitor is storing electric energy just as a battery might store chemical energy.



Capacitors in Circuits

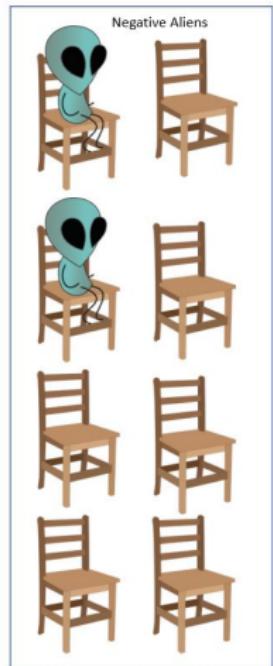
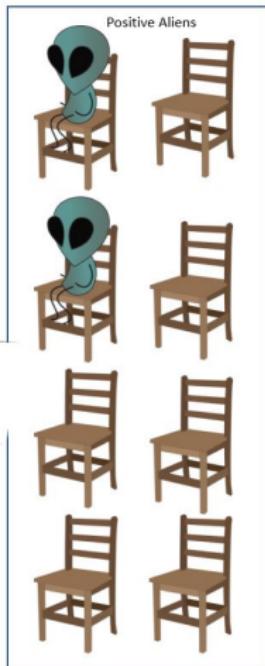
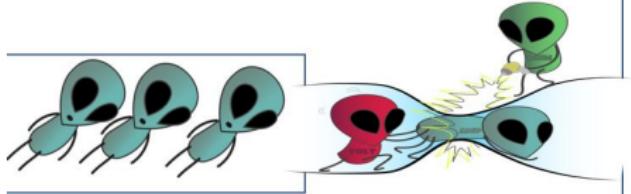




Capacitors in Circuits

Larger values of R and C

Direct Current





RC Time Constant

Capacitance is defined as:

$$C = \frac{Q}{V} \left(\frac{\text{Coulombs}}{\text{Volt}} \right)$$

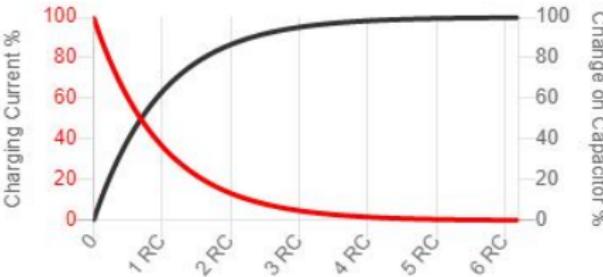
The current through a capacitor is:

$$I = C \frac{\Delta V}{\Delta t}$$

And, therefore, the capacitor charges with a time constant (τ):

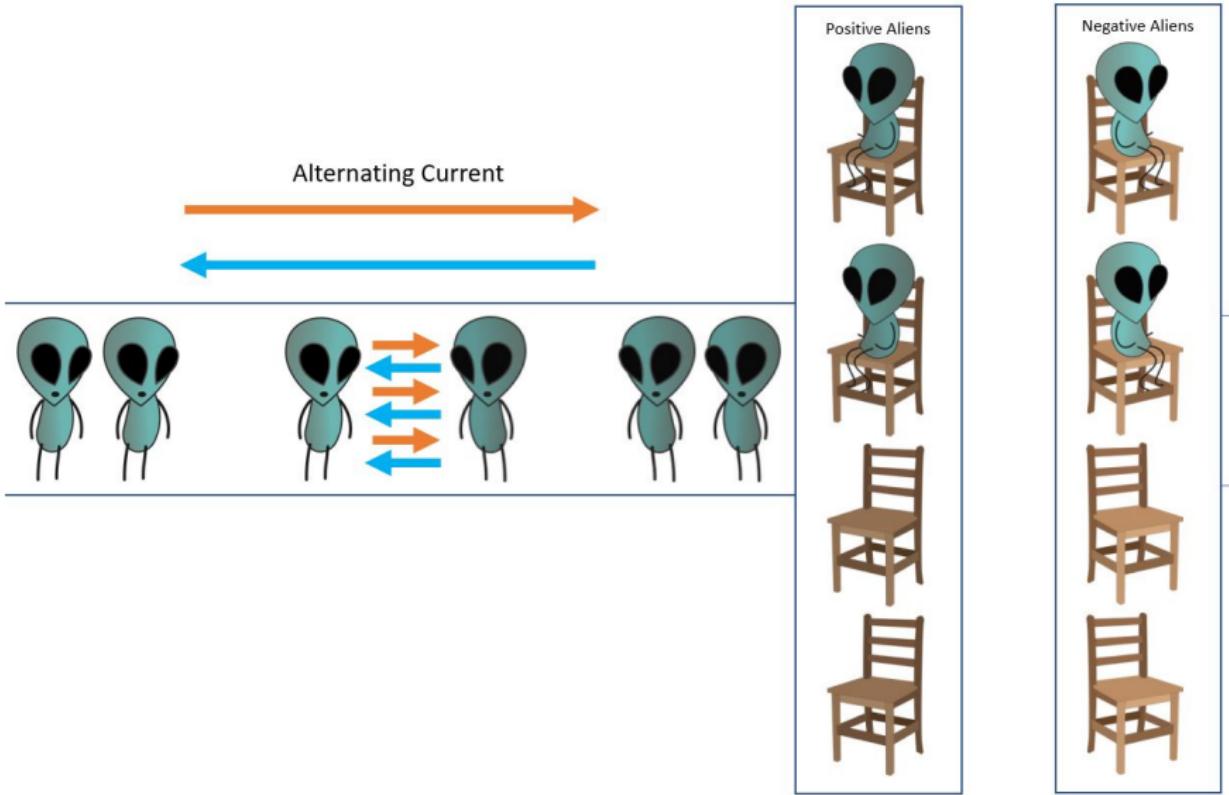
$$\tau = RC$$

$$V_c(t) = V_c(0) * e^{-\frac{t}{\tau}}$$





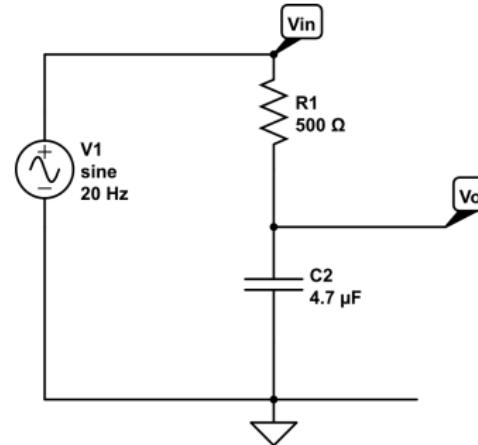
Alternating Current





Low Pass Filter - cutoff frequency f_c

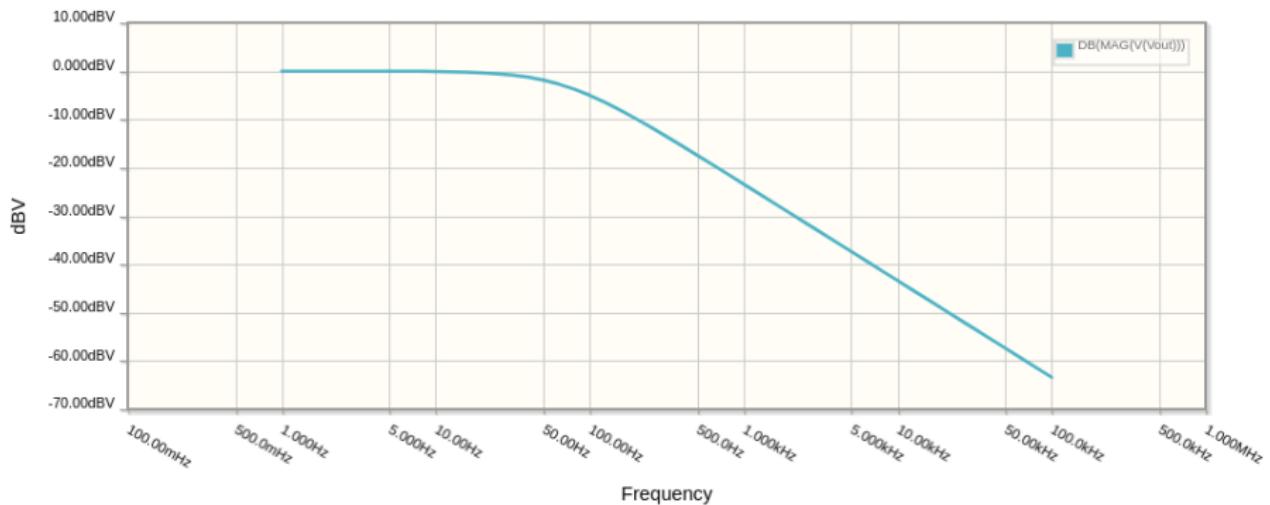
- At low frequencies, there is plenty of time for the capacitor to charge up to practically the same voltage as the input voltage.
- At high frequencies, the capacitor only has time to charge up a small amount before the input switches direction. The output goes up and down only a small fraction of the amount the input goes up and down. At double the frequency, there's only time for it to charge up half the amount.



$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$



Low Pass Filter Response



$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(500)(4.7 \times 10^{-6})} = 67.5678 \text{ Hz}$$



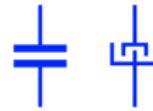
Capacitors - does it matter how they are placed

- Some types of capacitors (electrolytic and tantalum) are polarized (they have + and - terminals). This is due to how the dielectric film has been deposited. The reverse polarity leads to degradation of the dielectric.
- Other capacitors (ceramic and film) do not have a polarity and can be installed in either direction.

Polarized Electrolytic Capacitor

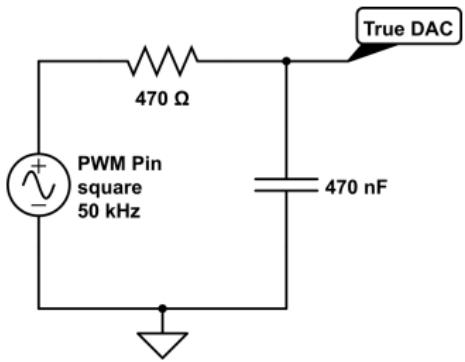


Generic Capacitor





True DAC on Photon 2



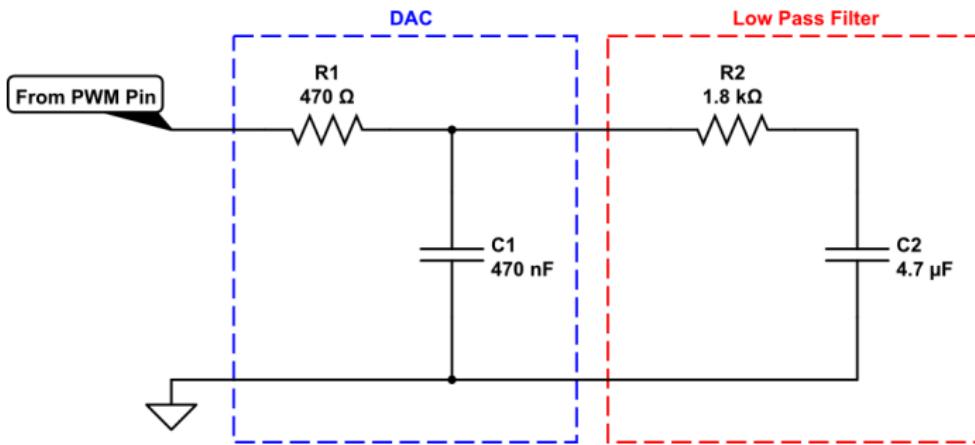
`analogWrite(pin, value, frequency)`

The Particle microcontrollers do not have a true DAC (Digital to Analog Converter). However, we can convert a PWM pin to a DAC signal using a low pass filter.

- The PWM signal oscillates at 500 Hz, but we can increase up to 50,000 Hz using a third parameter in `analogWrite()`.
- Using $R = 470\Omega$ and $C = 0.47\mu F$ will give a $f_c = 720\text{Hz}$.



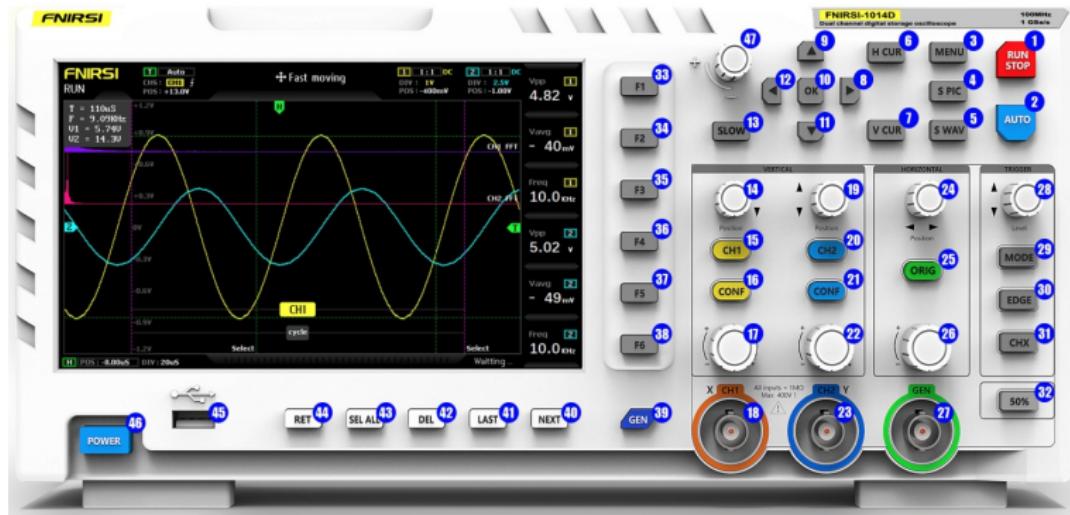
Low Pass Filter from PWM Pin



For the above values: $f_c(\text{DAC}) = 720\text{Hz}$ and $f_c(\text{LowPass}) = 18\text{Hz}$



2 Channel Oscilloscope - FINIRSI-1014D



- 18(23) - Channel 1(2) Input Port
- 17(22) - Channel 1(2) Amplitude
- 14(19) - Channel 1(2) Position
- 15(20) - Channel 1(2) On/Off
- 26 - Time base adjustment
- 28 - Trigger adjust
- 2 - Auto Adjust
- 46 - On/Off



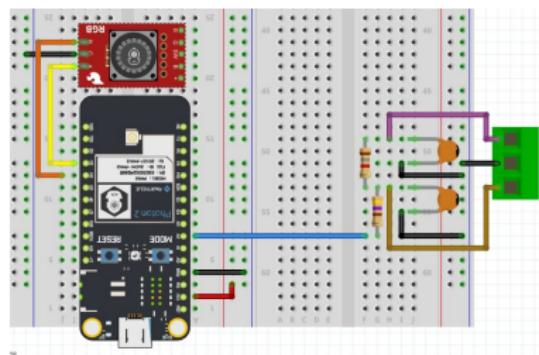
Assignment: L05_05_Oscilloscope



- ➊ Copy code from L02_03_HelloLEDAnalog
 - Change the delay to *5000ms*.
 - Use pin D13 for the LEDPIN.
- ➋ Measure D13 with the voltmeter
- ➌ At the same time, also measure D13 with the Oscilloscope
- ➍ Save a picture of the oscilloscope trace to the github repository
- ➎ Extra
 - Using the LED oscillator from day one, measure the voltage on the middle leg of both transistors using the oscilloscope.
 - Speculate in your notebook, why do the voltages behave the way they do?



Assignment: L05_06_lowPass



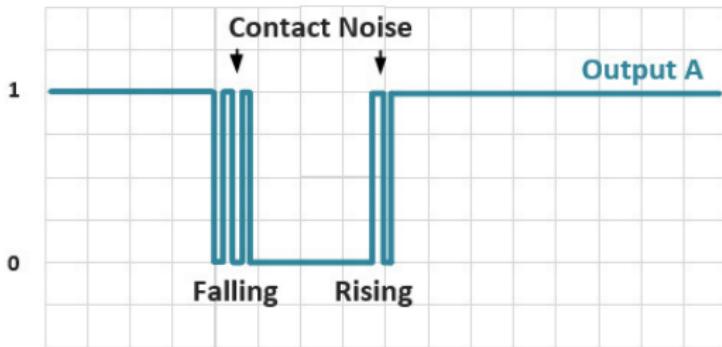
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

`analogWrite(pin, value, freq)`

- ① Create a DAC with a $f_c \approx 700\text{Hz}$
- ② Create a low pass filter after the DAC with a $f_c \approx 18\text{Hz}$
- ③ Copy and modify code from L02_05_HelloLEDSin
 - Use D13 for the LEDPIN and connect it to the DAC
 - Use the encoder to vary the sine wave frequency from 5 to 50 Hz
 - Modify analogWrite to change the PWM frequency (3rd parameter) to 50,000 Hz
- ④ Measure before and after the low pass filter with the oscilloscope. Record the change in magnitude and phase in lab notebook

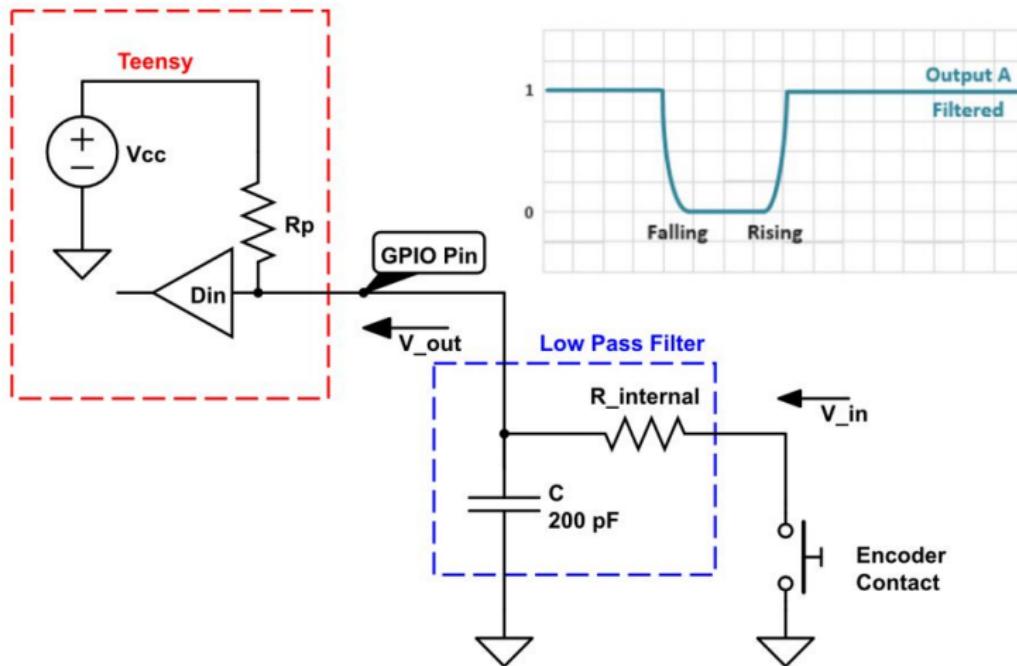


Encoder Jitter



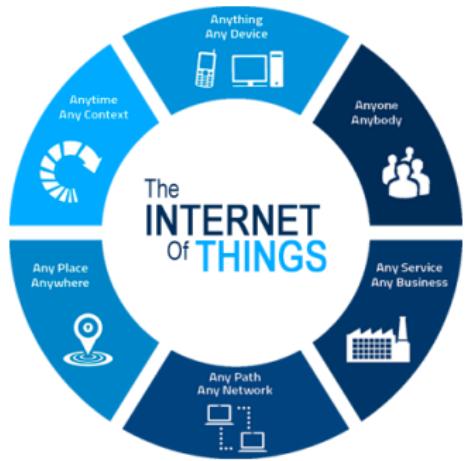


Encoder - Low Pass Filter





Module 5 Review

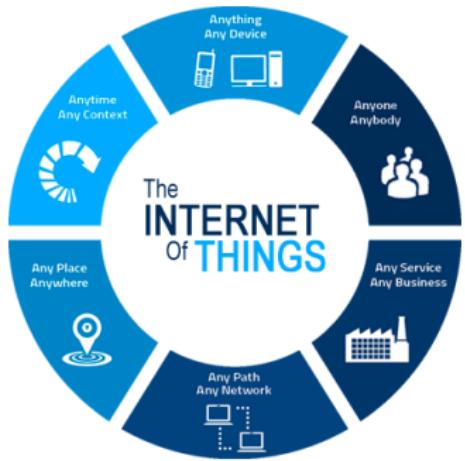


- Learning Objectives
 - ① Encoders
 - ② Capacitors
 - ③ Oscilloscopes
 - ④ Low Pass Filters
- Additional Items
 - ① 3D Modeling Lesson 2 - Spur Gear

Module 6 - Servo



Module 6 Objectives



- Learning Objectives

- 1 Servo Motors
- 2 KeyPad
- 3 2-dimensional arrays
- 4 Char and Byte data types / ASCII
- 5 Reverse Engineering

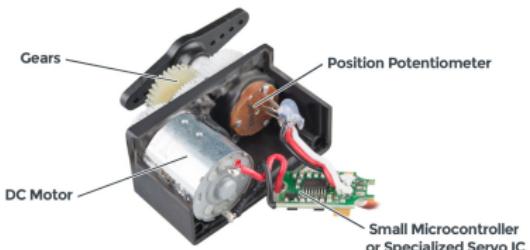
- Additional Items

- 1 Quiz 4



Servo Motors

- A servo is any motor-driven system with a feedback element built in.
- A servo motor basically has three core components:
 - ① a DC motor,
 - ② a potentiometer that measures its position,
 - ③ a feedback controller circuit
- The servo is controlled by a PWM signal from a digital pin. The width of the pulse determines the position that the servo moves to.





Servo library

The Particle has the Servo class built-in, so no library is needed.

① Header

- Servo myServo; - create object myServo of class Servo

② void setup()

- myServo.attach(pin) - attach the Servo object to a pin (this must be a PWM pin)

③ void loop()

- myServo.write(angle) - move servo to angle (in degrees)



Assignment: L06_Servo



① L06_01_Servo

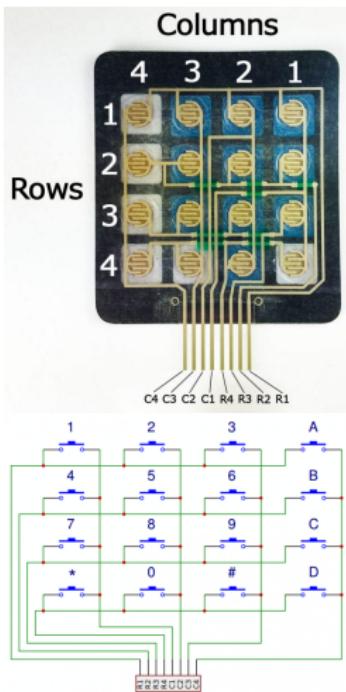
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- Connect the servo and a button to the Particle
- Create a HelloServo-type code that moves the servo to 180 degrees, waits, and then moves it to zero.
- Modify the code to have the servo oscillate between 0 and 180 degrees using a sine wave pattern.
- Have the button to start and stop the motion.
- Extra: Have the motion begin again at the point in the cycle where it stops.

Recall, in C++ (`math.h`) the math constants are `M_<name>`. For example, `M_PI` = π .



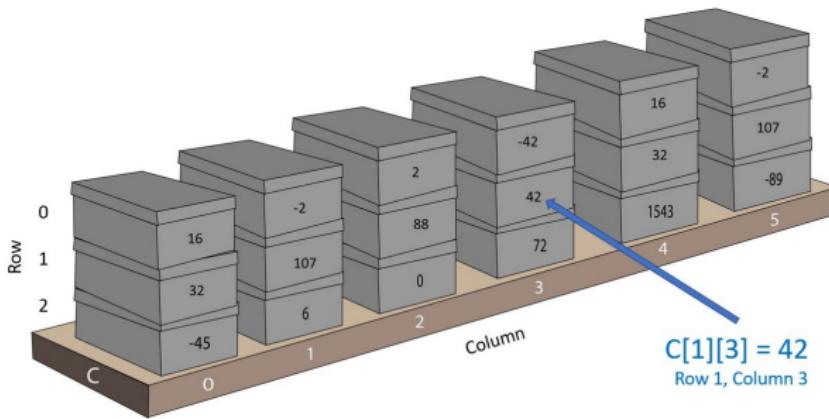
KeyPad



- The Keypad is a two-dimensional array of buttons.
- Pushing a button connects one row pin with one column pin.
- We will use the Keypad_Particle.h library to access the Keypad.
- NOTE: due to the onboard LED, you can not use Pin D7 for the keypad



2-dimensional arrays



- Declare Array: `int c[3][6] = {{16,-2,2,-42,16,-2},{32,107,88,42,32,107},{-45,6,0,72,1543,-89}};`
- Set a Cell: `c[1][3] = 42;`
- Access a Cell: `x = c[1][3]; → x = 42`



Char and Byte Datatype

- The char data type is a single byte in size and can be used to represent text characters (ASCII).
- Alternatively, the datatype byte can also be used for a single byte (8-bit number)

ASCII TABLE

Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char
0	0	[NULL]	32	20	[SPACE]	64	40	@	96	60	`
1	1	[START OF HEADING]	33	21	!	65	41	A	97	61	a
2	2	[STRUCTURE TEXT]	34	22	“	66	42	B	98	62	b
3	3	[END OF TEXT]	35	23	#	67	43	C	99	63	c
4	4	[END OF TRANSMISSION]	36	24	\$	68	44	D	100	64	d
5	5	[ENQ/UART]	37	25	%	69	45	E	101	65	e
6	6	[ACKNOWLEDGE]	38	26	&	70	46	F	102	66	f
7	7	[PRINT]	39	27	*	71	47	G	103	67	g
8	8	[BACKSPACE]	40	28	(72	48	H	104	68	h
9	9	[HORIZONTAL TAB]	41	29)	73	49	I	105	69	i
10	A	[LINE FEED]	42	2A	*	74	4A	J	106	6A	j
11	B	[VERTICAL TAB]	43	2B	+	75	4B	K	107	6B	k
12	C	[FORM FEED]	44	2C	,	76	4C	L	108	6C	l
13	D	[CARRIAGE RETURN]	45	2D	-	77	4D	M	109	6D	m
14	E	[SOFT DLE]	46	2E	=	78	4E	N	110	6E	n
15	F	[SOFT ENQ]	47	2F	/	79	4F	O	111	6F	o
16	10	[DATA LINK ESCAPE]	48	30	0	80	50	P	112	70	p
17	11	[DEVICE CONTROL 1]	49	31	1	81	51	Q	113	71	q
18	12	[DEVICE CONTROL 2]	50	32	2	82	52	R	114	72	r
19	13	[DEVICE CONTROL 3]	51	33	3	83	53	S	115	73	s
20	14	[DEVICE CONTROL 4]	52	34	4	84	54	T	116	74	t
21	15	[NEGATIVE ACKNOWLEDGE]	53	35	5	85	55	U	117	75	u
22	16	[SYNCHRONOUS IDLE]	54	36	6	86	56	V	118	76	v
23	17	[END OF TRAN BLOCK]	55	37	7	87	57	W	119	77	w
24	18	[SOFT XON]	56	38	8	88	58	X	120	78	x
25	19	[END OF MEDIUM]	57	39	9	89	59	Y	121	79	y
26	1A	[SUBSTITUTE]	58	3A	:	90	5A	Z	122	7A	z
27	1B	[ESCAPE]	59	3B	;	91	5B	{	123	7B	{
28	1C	[FILE SEPARATOR]	60	3C	<	92	5C	\	124	7C	\
29	1D	[GROUP SEPARATOR]	61	3D	=	93	5D]	125	7D	}
30	1E	[RECORD SEPARATOR]	62	3E	>	94	5E	^	126	7E	-
31	1F	[UNIT SEPARATOR]	63	3F	?	95	5F	-	127	7F	[DEL]

ASCII: American Standard Code For Information Interchange

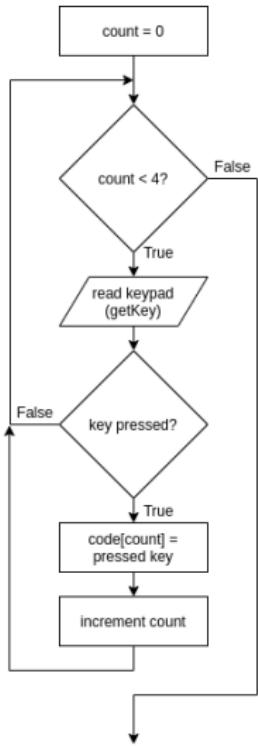


Keypad_Particle.h

```
1 #include <Keypad_Particle.h>
2
3 const byte ROWS = 4;
4 const byte COLS = 4;
5 char customKey;
6
7 char hexaKeys[ROWS][COLS] = {
8     {'1', '2', '3', 'A'},
9     {'4', '5', '6', 'B'},
10    {'7', '8', '9', 'C'},
11    {'*', '0', '#', 'D'}
12};
13
14 byte rowPins[ROWS] = {D8,D9,D16,D15}; // 1st to 4th Keypad pins (starting on left)
15 byte colPins[COLS] = {D17,D18,D19,D14}; // 5th to 8th Keypad pins
16
17 Keypad customKeypad = Keypad(makeKeymap(hexaKeys), rowPins, colPins, ROWS, COLS);
18
19 void setup(){
20     Serial.begin(9600);
21     waitFor(Serial.isConnected,10000);
22 }
23
24 void loop(){
25     customKey = customKeypad.getKey();
26
27     if (customKey){
28         Serial.printf("Key Pressed: %c\n",customKey);
29         Serial.printf("Key Pressed (Hex Code) 0x%02X\n",customKey); //ASCII Hex value
30     }
31 }
```



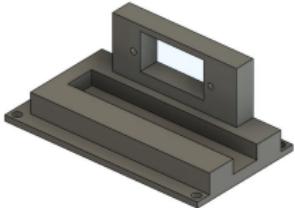
While Loop Application - entering code from keypad



- Entering a code from a keypad is an example of a condition-based loop, as it can't be predicted when the user will press a key
- Up until now, most loops in the class have been For Loops; however, for a condition-based loop a While Loop is more appropriate
- In the flow chart to the left:
 - Loop until 4 keys are pressed
 - Use getKey() to get a key if one is pressed
 - If the key is pressed then store it and increment count



Assignment: L06_02_Lock



- Notebook:
schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- ➊ Design and print a lockholder based on the class example.
 - Optional: design and print your own gear and lock slider
- ➋ Using the keypad, create a digital lock
 - Implement 4-digit digital "key" in an array.
 - Use the keypad to enter a code and store the entered code in an array
 - Create a bool function^a that compares entered code array to the key array
 - Use the servo to lock and unlock based on a correctly entered code.
 - Light green LED and disengage lock when unlocked.
 - Light red LED and engage lock when locked.

^aRemember to use local variables in the function



Assignment: L06_03_LockPick (Extra Credit)

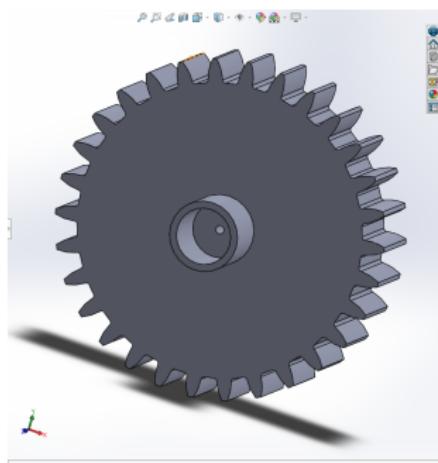
- ① Create a new project.
- ② Create an electronic lock pick
 - Set servo to locked position.
 - Implement 4-digit digital "key" in an array as before.
 - Automatically generate a random guess at the "key"
 - Using your bool function compares random code array to the key array
 - Repeat until correct, and then open lock.
 - Print the number of guesses and the microseconds (micros()) taken from first guess to correct guess.
 - Using the reset button, run the entire code 10 times and document the variation in time to find the correct code.



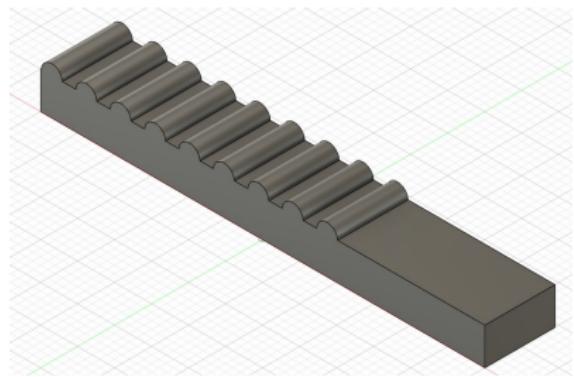


Optional Designs

GEAR

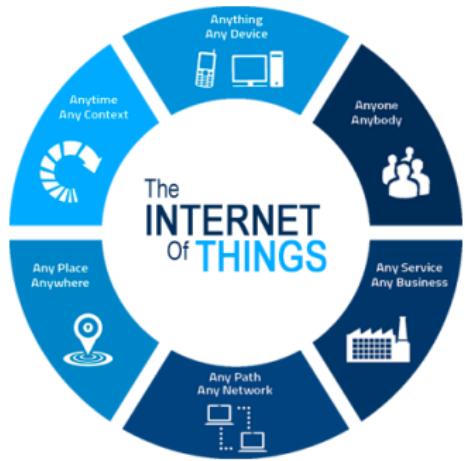


LOCK SLIDER





Module 6 Review



- Learning Objectives

- 1 Servo Motors
- 2 KeyPad
- 3 2-dimensional arrays
- 4 Char and Byte data types / ASCII
- 5 Reverse Engineering

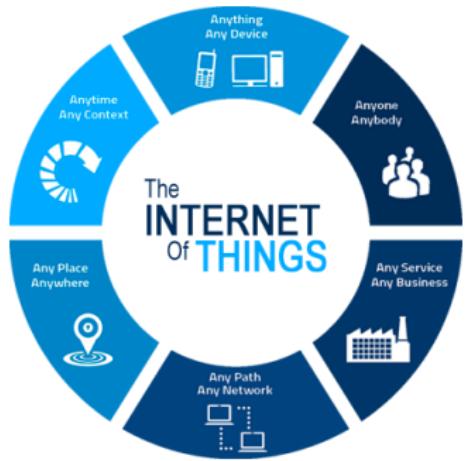
- Additional Items

- 1 Quiz 4

Module 7 - I^2C



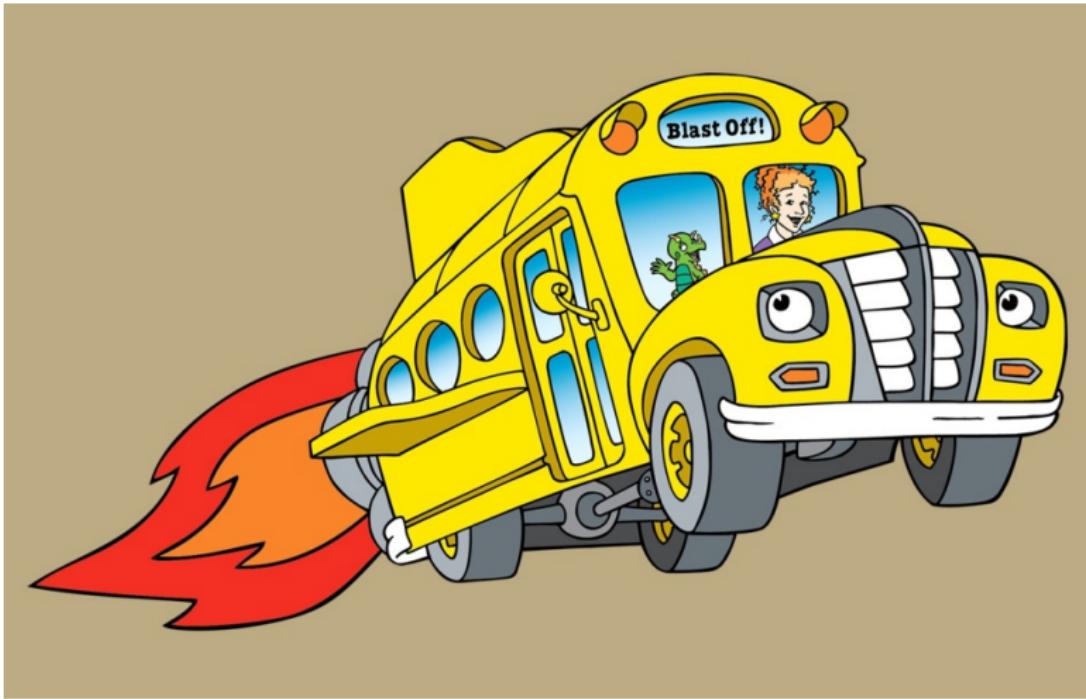
Module 7 Objectives



- Learning Objectives
 - ① Buses / I^2C
 - ② OLED / BME
- Additional Items
 - ① 3D Modeling Lesson 4 - Flowerpot

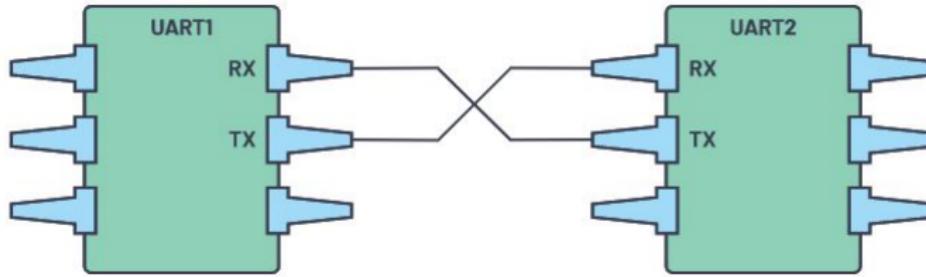


Buses and Interfaces





UART

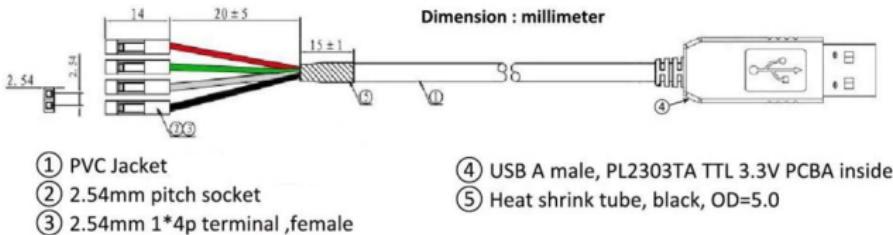


Universal Asynchronous Receiver/Transmitter

- Each device have a transmit (Tx) and receive (Rx) pin.
- UART1 Tx is connected to UART2 Rx (and visa versa)



The USB Cable is a UART connection

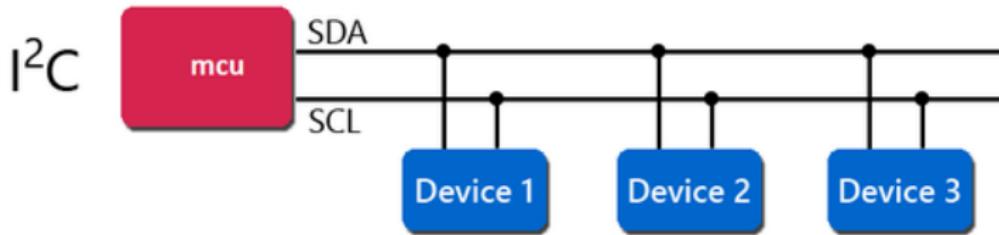


1*4P Female Socket	Name	Colour	Description
Pin 1	TXD	White	Transmit Asynchronous Data
Pin 2	RXD	Green	Receive Asynchronous Data
Pin 3	GND	Black	Device ground supply
Pin 4	VCC	Red	+5V





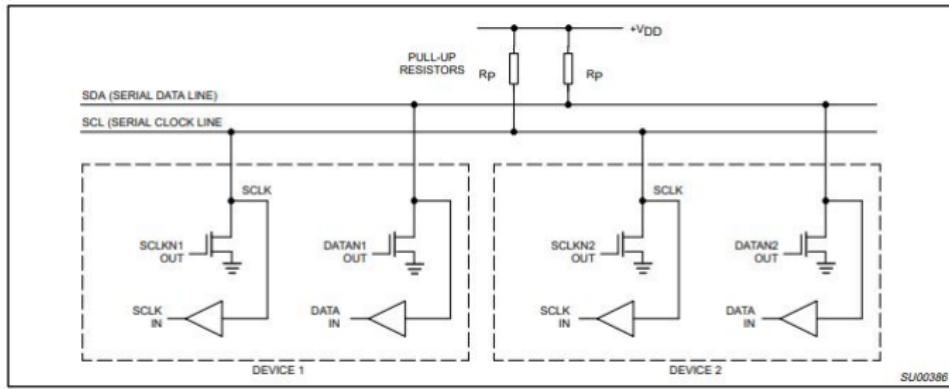
Inter-integrated Circuit (I^2C)





I^2C Pullup Resistors

The I^2C drivers are "open drain". They can pull the corresponding signal line low, but cannot drive it high. This is done to prevent a short when one device is driving the bus low, while another is driving it high.

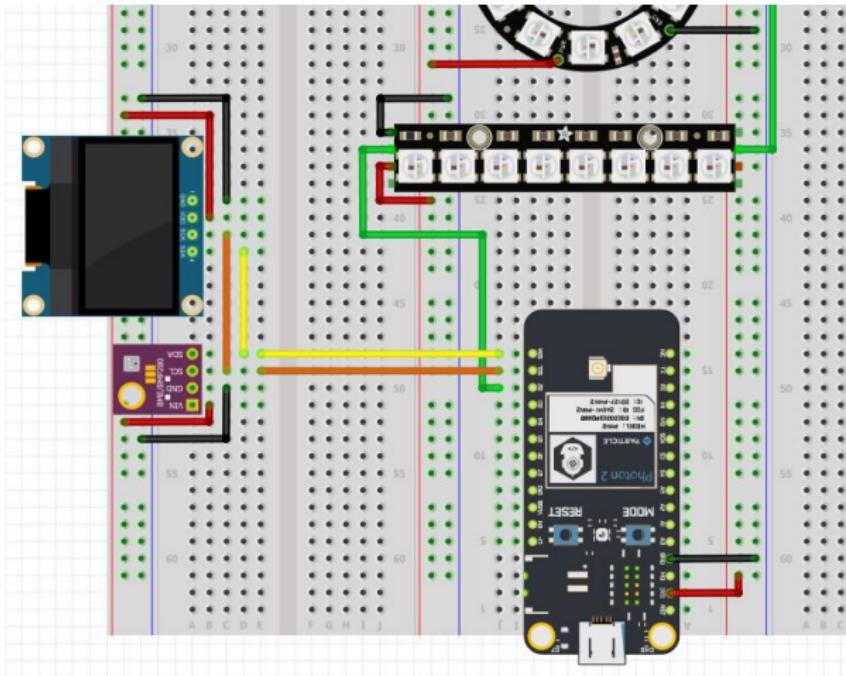


Each I^2C line needs a pull-up resistor on it to restore the signal to high when no device is asserting it low. Photon 2 has internal pull-up resistors that are usually sufficient to restore the high signal. For I^2C greater than 1m, an external 4.7k Ω should be added to each line.



Adding OLED and BME280 to Breadboard

NOTE: VCC and GND may be switched on your components. Make sure GND is wired to Ground and not 3.3V.





L07_00_I2CScanner

Let's create an I2C scanner

- ① On your large breadboard, add the BME280 and OLED.
- ② Follow along to create the I2C code.
 - Use library wire.h
 - Wire.begin();
 - Wire.beginTransmission(i);
 - Wire.endTransmission();
 - 0: Transmission Successful
 - 1: Data too long to fit in transmit buffer
 - 2: Received NACK (Negative Acknowledgment) on transmit of address
 - 3: Received NACK on transmit of data
 - 4: Other error
- ③ Determine the I2C addresses of each device, document in your lab notebook.



Char Datatype - Revisited

Reminder - the char data type is a single byte in size and can be used to represent text characters (ASCII).

ASCII control characters		ASCII printable characters		Extended ASCII characters	
00	NULL (Null character)	32	space	64	Ø
01	SOH (Start of Header)	33	!	65	A
02	STX (Start of Text)	34	"	66	B
03	ETX (End of Text)	35	#	67	C
04	EOT (End of Trans.)	36	\$	68	D
05	ENQ (Enquiry)	37	%	69	E
06	ACK (Acknowledgement)	38	&	70	F
07	BEL (Bell)	39	'	71	G
08	BS (Backspace)	40	(72	H
09	HT (Horizontal Tab)	41)	73	I
10	LF (Line feed)	42	*	74	J
11	VT (Vertical Tab)	43	+	75	K
12	FF (Form feed)	44	-	76	L
13	CR (Carriage return)	45	.	77	M
14	SO (Shift Out)	46	,	78	N
15	SI (Shift In)	47	/	79	O
16	DLE (Data link escape)	48	0	80	P
17	DC1 (Device control 1)	49	1	81	Q
18	DC2 (Device control 2)	50	2	82	R
19	DC3 (Device control 3)	51	3	83	S
20	DC4 (Device control 4)	52	4	84	T
21	NAK (Negative acknowledgement)	53	5	85	U
22	SYN (Synchronous idle)	54	6	86	V
23	ETB (End of transmission block)	55	7	87	W
24	CAN (Cancel)	56	8	88	X
25	EM (End of medium)	57	9	89	Y
26	SVD (Start of verbal data)	58	0	90	Z
27	ESC (Escape)	59	:	91	Ø
28	FS (File separator)	60	<	92	Ø
29	GS (Group separator)	61	=	93	Ø
30	RS (Record separator)	62	>	94	Ø
31	US (Unit separator)	63	?	95	-
127	DEL (Delete)				

ASCII 248	
Ø	alt + 248 (Degree symbol)
most consulted	
<ul style="list-style-type: none"> 1 érye, n with tilde (alt + 164) 2 black square (alt + 254) 3 superscript two, square (alt + 255) 4 degree symbol (alt + 248) 5 apostrophe, single quote (alt + 39) 6 letter Mu, miro, miornos (alt + 232) 7 copyright symbol (alt + 164) 8 registered trademark (alt + 169) 9 superscript three, cube (alt + 252) á a with acute accent (alt + 160) 	

```

1 const char degree = 0xF8; // Decimal 248 = 0xF8
2 float temp = 98.6;
3 void setup() {
4   Serial.begin(9600);
5   //NOTE: extended ASCII characters don't always print correctly to Serial Monitor
6   Serial.printf("My temperature is %0.1f %c", temp, degree);
7 }
```



A word about example code

Example code is sometime misleading as each author has their own style

- ① .print() and .println() vs. .printf()
 - Some arduino-type embedded controllers don't have .printf() available as a command, so .print() and .println() are used instead.
 - Per the IoT Style Guide, we use .printf()
- ② Serial.printf(F("Hello World"))
 - AMR Cortex is segmented into program memory and data memory.
 - The compiler usually stores Strings as constants in data memory.
 - The F() forces the String to be stored in program memory. This is useful when the data memory is "small"
 - The ARM Cortex compilers automatically store Strings in program memory, so F() is redundant and not needed.
- ③ #define pre-compiler directive
 - #define can be used to create a label that represents a value. Before compiling, the anywhere the label exists in the code, it is replaced by the value.
 - Our IoT Style guide is to use "const datatype NAME=value" instead of "#define NAME value"



Assignment: I^2C - L07_00_OLEDEExample



- Notebook:
schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- Open (using "Open Folder") and Flash the L07_00_OLEDEExample
- In your notebook document the commands to:
 - ① library that is needed to be installed
 - ② libraries to include
 - ③ declaration of the OLED object
 - ④ initialization the OLED object
 - ⑤ the various commands to display text

NOTE: the Adafruit_GFX library is installed as part of Adafruit_SSD1306 and should NOT be installed separately. However, it still has its own #include()



Assignment: I²C (Continued)



① L07_01_OLEDWrite

- Using your notes and the example, write code (do not cut/paste from the example) to display to the OLED:
 - Hello World
 - Your Name using spanish honorific (señor, señora, señorita).
 - Your Birthday (e.g., 04/03/1968) using separate variables for month, day, and year.
- Rotate screen using setRotation(rot) method.
 - rot is an int from 0 to 3
- Make your own bitmap and display on the screen
 - <https://www.reduceimages.com>
 - <https://marlinfw.org/tools/u8glib/converter.html>

- Notebook:
 - schematic
- Fritzing diagram
- Wire your circuit
- Write the code



Reduce Image to fit 128 x 64

The screenshot shows the homepage of [reduceimages.com](https://www.reduceimages.com). At the top, there's a navigation bar with links for 'Blog', 'Pricing', 'Login', and 'Get Premium'. Below the header, the main title 'Resize an Image' is centered. On the left, there's a preview area showing a small version of a cartoon turtle image with its original dimensions (240x203) and file size (12.78 KB). A blue 'Select Image' button is located below this preview. To the right, under the heading 'Choose new size and format', there are input fields for 'Width' (set to 78), 'Height' (set to 64), and 'Resolution' (set to 72). There are dropdown menus for 'Format' (set to 'JPG'), 'Quality' (set to 90%), and 'Background' (set to a light blue circle). A large blue 'Resize Image' button is at the bottom of this section.

<https://www.reduceimages.com>



Bitmap Generator

```
/* Made with Marlin Bitmap Converter
 * https://marlinfw.org/tools/u8glib/converter.html
 *
 * This bitmap from the file 'tmtt (1).jpg'
 */
#pragma once

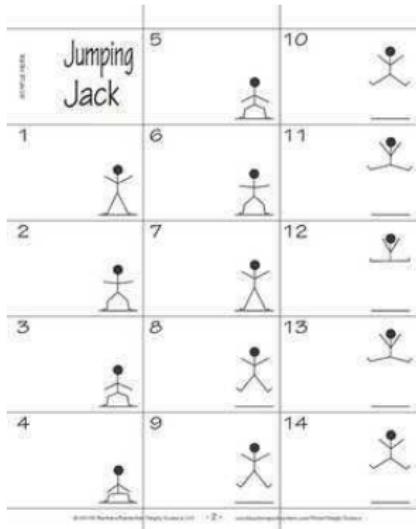
#define YWIKK_BMPWIDTH 78
#define YWIKK_BMPHEIGHT 64

const unsigned char bitmap_ywikk[] PROGMEM = {
    0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,
    0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x01, 0x00,
    0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,
    0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,
    0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00
};
```

- <https://marlinfw.org/tools/u8glib/converter.html>
- Select Marlin 1.x
- Select Bitmap
- Select nothing on the third row
- Copy the bitmap constant (const unsigned char ...)



L07_03_JumpingJackFlash (Extra Credit)



① Using the SSD1306 Draw functions:

- Create at least 5 different stick figure jumping jack frames
- Use the frames to create an animation.

② Add in Encoder functionality

- Use the encoder switch to change between auto and manual
- In auto, have the encoder change the speed of the animation
- In manual, manually step through each frame with the encoder.



Using the Adafruit_BME280 class

```
1 // Include the Library
2 #include "Adafruit_BME280.h"
3
4 // Define BME280 object
5 Adafruit_BME280 bme; //this is for I2C device
6
7 // Initialize the BME280 in void setup()
8 status = bme.begin(hexAddress);
9 if (status == false) {
10     Serial.printf("BME280 at address 0x%02X failed to
11     start", hexAddress);
12 }
13
14 // Getting data from BME280
15 tempC = bme.readTemperature(); //deg C
16 pressPA = bme.readPressure(); //pascals
humidRH = bme.readHumidity(); //%RH
```



Assignment: I^2C



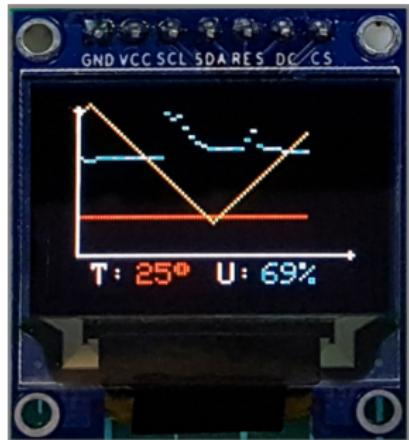
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1 L07_02_BME280

- Read BME280 data and print to Serial Monitor.
- Convert temperature and pressure to tempF and inHg.
- Modify code to print the converted values and humidity to Serial Monitor and the OLED display twice per second using the IoTTimer.
- Use your NeoPixels to give a visual indication of room conditions (temperature, pressure, and humidity).



More Display Integration



① L07_04_Plotter (Extra Credit)

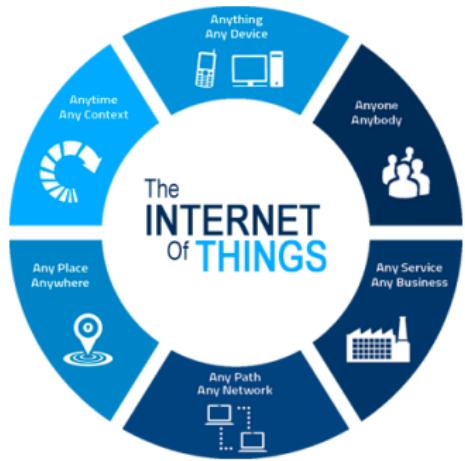
- Plot temperature vs time on the SSD1306 display.
- One data point every 100ms
- Display temperature and humidity at the bottom of the display
- Test using your finger for warmth, and frozen water bottle for cold

② L07_05_Pong (Extra Credit)

- Create a paddle that moves with the encoder
- Create a ball in motion, including bouncing off walls and paddle.



Module 7 Review

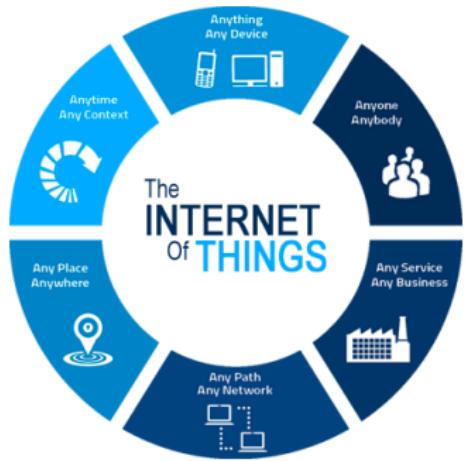


- Learning Objectives
 - ① Buses / I^2C
 - ② OLED / BME
- Additional Items
 - ① 3D Modeling Lesson 4 - Flowerpot

Module 8 - Internet



Module 8 Objectives



- Learning Objectives
 - ① IP / MAC Addresses
 - ② Wemo
 - ③ Hue Lights
- Additional Items
 - ① Quiz 5



The Internet

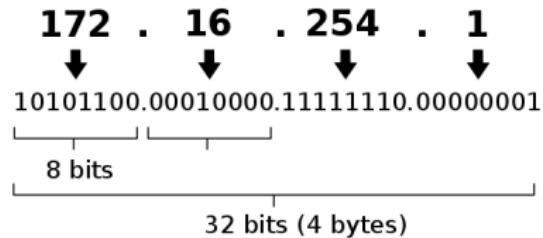




IP Addresses

- When a device joins the network, it is given an internet address.
 - static or dynamic
- IPv4 (32-bit) - 4.2 billion
- IPv6 (128-bit) - $340 * 10^{27}$ (quadrilliard)
- In Git Bash: ipconfig -all
- In Powershell: ipconfig /all
- In Terminal (MAC/Linux): ifconfig

IPv4 address in dotted-decimal notation



An IPv6 address

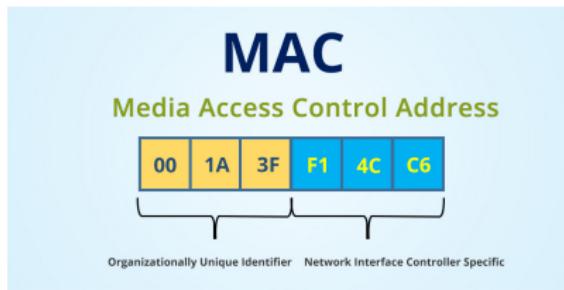
(in hexadecimal)
2001:0DB8:AC10:FE01:0000:0000:0000:0000

↓ ↓ ↓ ↓
2001:0DB8:AC10:FE01:: Zeroes can be omitted

00100000000001:00001101011000:1010110000010000:1111110000000001:
0000000000000000:0000000000000000:0000000000000000:0000000000000000



MAC Address



A MAC Address is a unique 6-byte (48-bit) address that is usually permanently burned into a network interface card (NIC) and uniquely identifies the device on an Ethernet-based network. The uniqueness of MAC addresses is ensured by IEEE.



Finding MAC Address

```
1 SYSTEM_MODE(SEMI_AUTOMATIC)
2 byte mac[6];
3
4 void setup() {
5
6     WiFi.on();
7     WiFi.connect();
8     while(WiFi.connecting()) {
9         Serial.printf(".");
10        delay(250);
11    }
12    Serial.printf("\nWaiting for IP Address\n");
13    delay(1000);
14    Serial.printf("Scan Particle for WiFi Information \n");
15    Serial.printf("ip address: %s \n", WiFi.localIP().toString().c_str());
16    WiFi.macAddress(mac);
17    Serial.printf("mac: %02X:%02X:%02X:%02X:%02X:%02X \n", mac[0], mac[1], mac[2], mac[3], mac
18 [4], mac[5]);
```

Serial monitor opened successfully:

```
.....
Waiting for IP Address
Scan Argon for WiFi Information
ip address: 10.0.0.25
mac: C8:2B:96:B5:30:88
```



Forcing Connection to Specific Network

In finding your IP address, you connected to DDCIOT (strongest signal). If there are multiple networks and we want to force connection to a specific network:

```
1 SYSTEM_MODE(MANUAL);
2
3 void setup() {
4     Serial.begin(9600);
5     waitFor(Serial.isConnected,15000);
6
7     WiFi.on();
8     WiFi.clearCredentials(); //prevent from connecting to DDCIOT
9     WiFi.setCredentials("IoTNetwork");
10    // If network requires a password
11    // setCredentials(const ""NetworkName", "Password");
12
13    WiFi.connect();
14    while(WiFi.connecting()) {
15        Serial.printf(".");
16    }
17    Serial.printf("\n\n");
```



Assignment: Wemo



- Schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① L08_01_HelloWemo

- Use the wemo example in IoTClassroom_CNM library as a template.
- Use a button to toggle Wemo on/off (one toggle per press)

② L08_02_WemoTimer (EXTRA CREDIT)

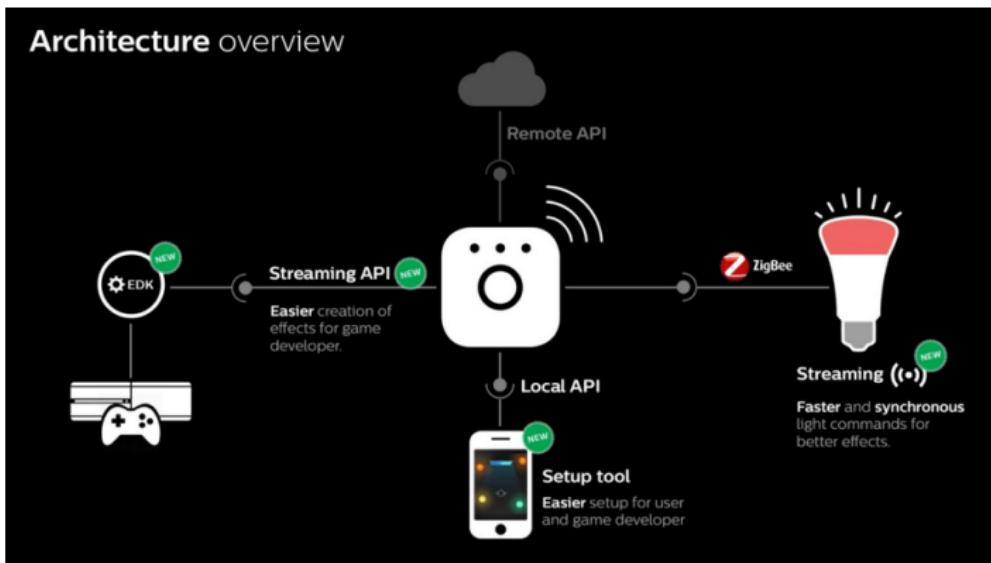
- Implement a method to select different Wemo (encoder, second button, etc.)
- Create timer that turns off a Wemo 10 secs after you push "off" button without using delay().

③ L08_03_Wemo_Object (EXTRA CREDIT)

- Copy wemo.h to wemoObj.h
- Modify it to be use Class and Methods.
- Modify your code to use a wemoObj object.



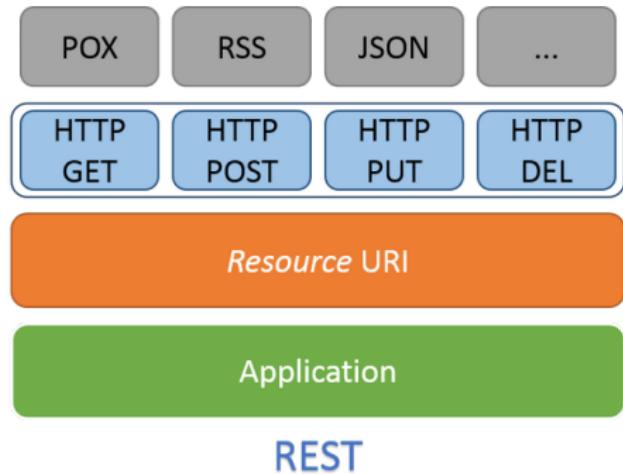
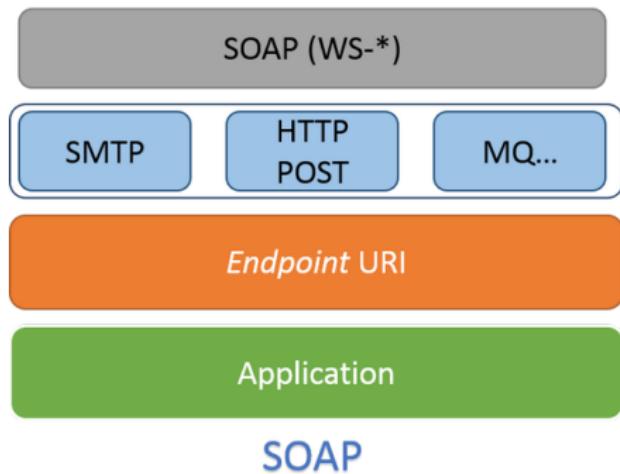
Phillips Hue API



Application Programming Interface: a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.

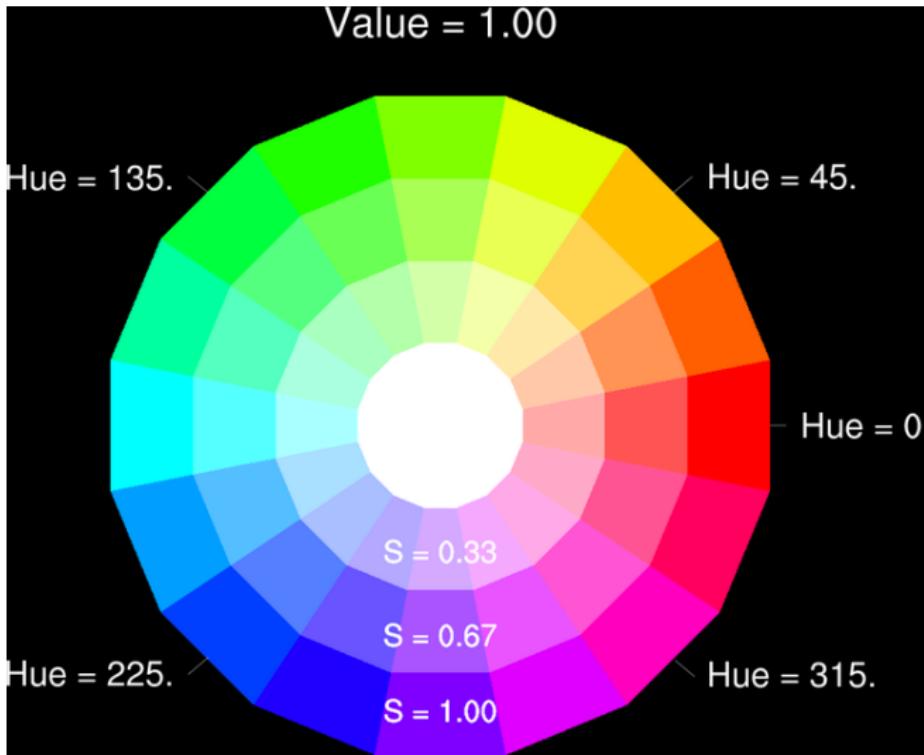


SOAP vs REST





HSV Colors





Assignment: L08_04_Hue



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

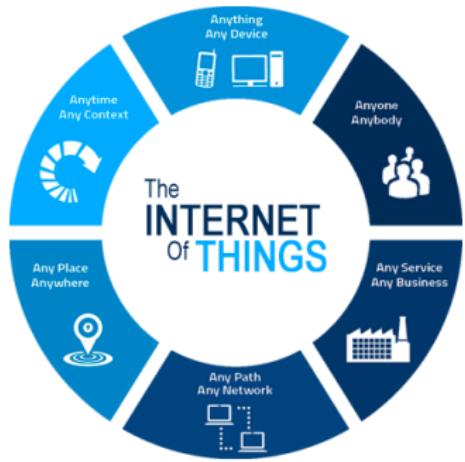
① Using the hue example in IoTClassroom_CNM library as a template:

- in setup() initializes color to red, brightness to half max, saturation to full, and turns on the light
- add a button that turns on and off the Hue light at your pod
- use the encoder to change the brightness of the Hue bulb,
- add a second button for cycling the Hue light through the colors of the rainbow.

Caution: sending commands to the Hue hub too quickly fills the buffer and leads to sluggish response. The hue.h library has been written to reject commands that match the previous command.



Module 8 Review



- Learning Objectives
 - ① IP / MAC Addresses
 - ② Wemo
 - ③ Hue Lights
- Additional Items
 - ① Quiz 5

Midterm 1 - Smart Room Controller



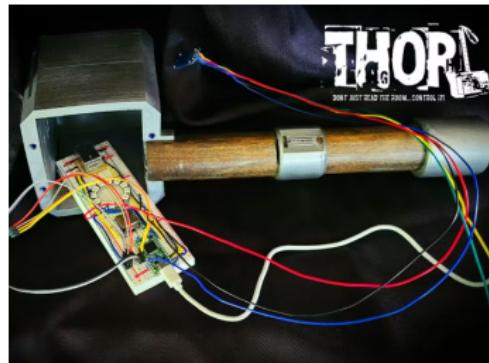
Smart Room Controller - Minimum Requirements

You are developing a Smart Room Controller prototype that you are going to pitch to a perspective investor.

- ① Control at least one Hue lights in the classroom
- ② Control at least two Wemo outlets in the classroom
- ③ Display dynamic messages on the OLED display
- ④ Use at least three additional components (LEDs, buttons, NeoPixels, Encoders, BME280, Servo motor, etc.)
- ⑤ Device has at least two modes
 - Manual - user controls lights and outlets
 - Automatic - external source triggers response of lights and/or outlet(s)
- ⑥ 3D design and print at least one part (button cover, knob, logo, etc.)
- ⑦ A component made at FUSE - laser, wood, metal (case, stand, etc.)
- ⑧ Extra Credit: use a component that we haven't learned in class
- ⑨ Extra Extra Credit: create a custom bitmap for your display



Smart Room Controller Examples





Project Plan - Template in Brightspace

Project Name:	Student Name:	Capstone Date:
Project Motivation and Overview:		
<p>Minimum Features:</p> <ul style="list-style-type: none">••••		
<p>Desired Features:</p> <ul style="list-style-type: none">••••		
<p>Stretch Goal Features:</p> <ul style="list-style-type: none">••••		
Anticipated Components:		
<ul style="list-style-type: none">••••		
Concerns and Considerations (Project Risks and Potential Mitigations)		
<ul style="list-style-type: none">•••		
Other Information:		

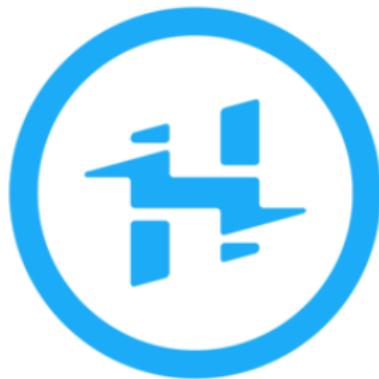


Project Plan (Gantt)

Project Implementation Timeline:							
Tasks	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Project Plan	X						
Presentation							



IoT Portfolio



- Create a hackster.io account.
- Follow barashap and edward-ishman
- Join the CNM Ingenuity channel



Uploading STL files to Hackster.io

The image contains two screenshots. The top screenshot shows a Sketchfab model of a grey LEGO brick labeled "Lego_brick V1". The bottom screenshot shows the "Attachments" section of a hackster.io project, where a "Link an existing repository" dialog box is open. The dialog box has a "Title" field containing "LegoBrick" and a "Comment" field containing "This is my lego". Below the comment is a "Repository link" field with the URL "https://sketchfab.com/3d-models/lego-brick-v1-1a6093be35fa4eccbc48a9ffea". At the bottom of the dialog are "Save changes" and "Cancel" buttons.

Lego_brick V1

Basics Team Things Story Attachments Go to project

Link an existing repository

Title: LegoBrick

Comment: This is my lego

* Repository link: <https://sketchfab.com/3d-models/lego-brick-v1-1a6093be35fa4eccbc48a9ffea>

Supported Autodesk Fusion 360, Sketchfab, Sketchup 3D Warehouse, Solidworks, Thingiverse, Youmagine

Save changes Cancel

- Go to sketchfab.com and create an account.
- Upload your .stl file^a
- Publish
- Go "See your Model" to get the URL
- In hackster.io under attachments, select "CAD - enclosures and custom parts"
- Then select "Link an existing repository"
- Use the sketchfab URL for your model

^afree account: only upload 10 per month



IoT Portfolio Github

Create a new repository

github.com

Central New Mexico... CNM Ingenuity ... EC Markdown

Search or jump to... Pull requests

brashap -

Top Repositories New

Find a repository...

ddc-lot/lg42
brashap/Phys1320
ddc-lot/class_slides
ddc-lot/instructor_guide

Join GitHub

Prepare for a career in tech. Campus. Global industry knowledge, industry tools, student community.

Under Security, change visibility to Public

Danger Zone

Change repository visibility
This repository is currently internal. Change visibility

Transfer ownership
Transfer this repository to another user or to an organization where you have the ability to create repositories. Transfer

Archive this repository
Mark this repository as archived and read-only. Archive this repository

Delete this repository
Once you delete a repository, there is no going back. Please be certain. Delete this repository

IMPORTANT: Do not forget to add in the .gitignore file

- Must include credentials.h, \target and nul
- Copy from any of the lessons



README.md

A README.md file to a repository to communicate important information about your project.

The README.md file typically includes:

- What the project does
- Why the project is useful
- How users can get started with the project
- A Revision History
- Who maintains and contributes to the project

The README.md is a great place to put a link to your Hackster.io



Markdown Language

The README.md is written in markdown language. Markdown was developed in 2004 by John Gruber in collaboration with Aaron Swartz.

Effect	Command
Italics	*Italics*
Bold	**Bold**
Heading 1	# Heading 1
Heading 2	## Heading 2
Link	[Link](http://a.com)
Image	![Image](http://url/a.png)
Local Image	![Image](/images/a.png)
List	<ul style="list-style-type: none">* item #1* item #2
Numbered List	<ol style="list-style-type: none">1 item #12 item #2



Edit README.md file

The README.md file can be edited locally (Notepad,TextEdit, etc.) and pushed like any other file.

Or, it can be edited online:

mod06_servo · Initial template

master · 1 Branch · 0 Tags

Go to file Add file Code About

No description, web

Images adding Images last year

.gitignore improved.gitignore 2 weeks ago

LICENSE.MD first commit last year

Lock Slider v2.stl updated parts 5 months ago

LockGear v2.stl updated parts 5 months ago

README.MD changed lesson number last year

smartlock.drawio.pdf added flowchart last month

README MIT license

Packages

edit README.md

Type to search

Code Issues Pull requests Actions Projects Wiki Security Settings

mod06_servo / README.md in master

Cancel changes Commit changes...

Spaces Soft wrap

1 //Deep Dive! / Lessons / 06_Web

2 # Web Service

3 4 IoT Class Repository for IOT IoT Session

5 In this lesson, learn how to use nodes and continue to build IoT design skills.

6

7

Edit README.md

Commit changes to save

After you edit, use git pull to synchronize your local repository with your github changes



Midterm Project - Smart Room Controller

- ① Determine functionality of your Smart Room Controller.
 - Use the components that we have learned over the last 3 weeks.
 - Get minimum requirements from the Instructor.
 - Use the Project Plan template to outline the functionality.
 - Draw flowcharts of the main functions you plan to implement.
 - Get feedback from at least 3 others on your planned functionality.
- ② Layout your circuitry in Fritzing along with a legible schematic.
- ③ Wire up your circuitry as if you're going to demo your controller for a perspective customer.
- ④ Code, debug, test.
- ⑤ Documentation and Demonstration:
 - Ensure all files are uploaded to GitHub with an appropriate README.md.
 - Upload your project to hackster.io.
 - Prepare a presentation/demonstration for the class on your controller.
 - Participate in class demonstrations.